GROWTH, PRODUCTIVITY AND ENERGY DYNAMICS OF *LEUCAENA* PLANTATIONS ON DEGRADED LANDS IN A SEMI - ARID REGION

Thesis submitted to the
Bundelkhand University, Jhansi (U.P.)

For the Degree of
DOCTOR OF PHILOSOPHY IN BOTANY

By

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1998

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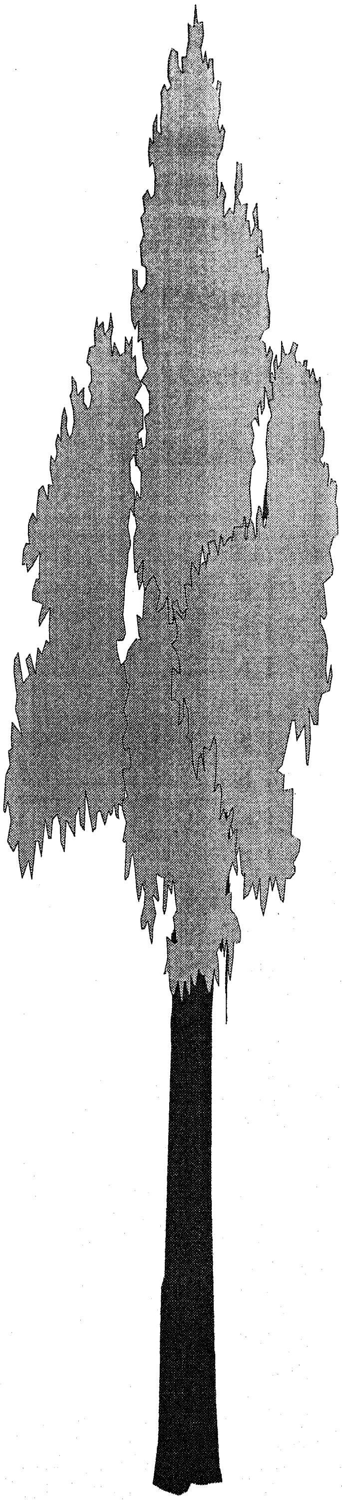
Declaration



I hereby declare that the thesis entitled " **Growth, productivity and energy dynamics of *Leucaena* plantations on degraded lands in a semi - arid region**" being submitted for the degree of **DOCTOR OF PHILOSOPHY** of the Bundelkhand University, Jhansi (U.P), India is an original research work carried out by me and no part of this work has been submitted for any degree or any other academic qualifications at any other university.

Seema Pathak

October 7,1998 **Seema Pathak**

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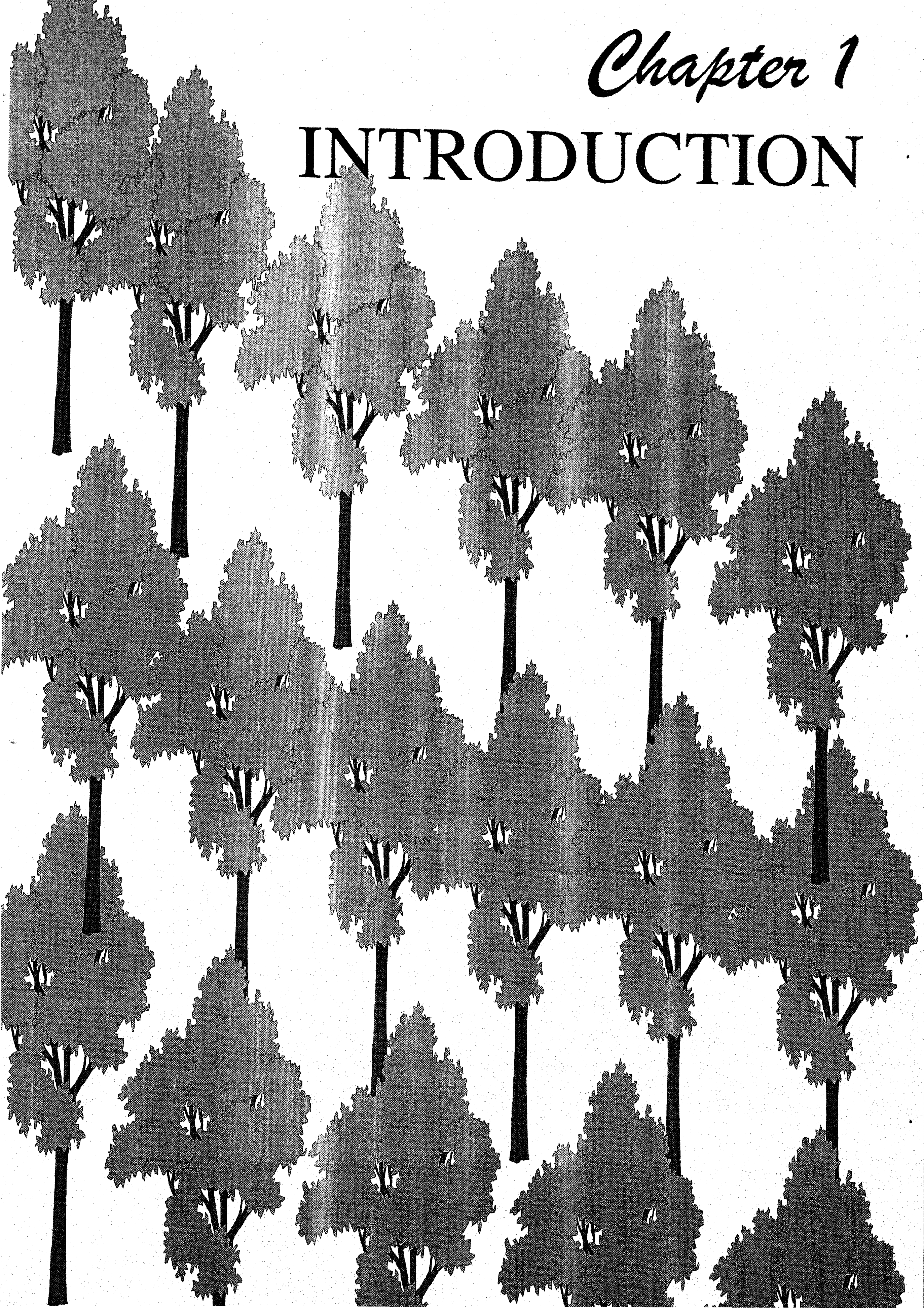

1

INTRODUCTION

India has a predominant agricultural land use. Its land area of 329 million hectare is facing serious problems of land degradation. The current land use shows 181.14 Mha under gross cropped area of which 139.52 Mha are net sown and 59.64 Mha gross irrigated. The area under forests is 63.888 Mha (State of Forest report, 1997, Forest Survey of India, Dehradun). The current situation of degraded lands in India shows 210 Mha area facing one or the other type of problem. Land degradation is a global problem. The Asian region has its much serious proportion.

Over population contributes to environmental problems such as atmospheric pollution, deforestation, global warming, acid rain, climatic changes, water scarcity, top soil erosion etc. According to Lester Brown of World Watch Institute farmers of the World have to grow food for 95 million more people every year using 25 million tonnes less of top soil. When the World population grows from some 5.3 billion now to 10 billion by 2050, the loss of fertile soil due to soil erosion every year on an average would lead to permanent food shortage.

The present human population of 940 million in India is expected to cross 1 billion by the beginning of next century when our food demands would be about 230 M t as against the current status of 192 M t. This will call for strategies of increasing per ha yield since area expansion will not be possible (Paroda 1996).

Livestock population reached 450 million in 1987 and is expected to have crossed 500 million by now. During past decades the population of sheep and goat has shown an increase of 40%. While the animal population status has shown steep rise, the grazing area and their production status has declined. The increasing animal pressure

on limited land resource is the serious threat to sustainability and prime cause of desertification. The loss of soil cover (vegetation) and increasing animal pressure accelerate soil erosion and run-off triggering the process of desertification. These processes have been studied in detail (Singh 1994).

As against the stipulated forest cover of 33.0 per cent, required to maintain ecological balance, we are left with 11.5 per cent of the total land area under tree cover. An additional 10.0 per cent of the land, measuring about 35 - 40 million ha belonging to the forest departments is either denuded or with less than 40 per cent canopy cover. The annual productivity of our forests is less than 1 cu m/ha as against the World average of 2.5. The damage to these fragile natural forests continues unchecked due to indiscriminate felling of trees, mining, development projects and uncontrolled grazing. Current annual removal of fuel wood from these forests is around 220 million tonnes against the production capacity of about 28 million tonnes (Anon 1996).

The per capita forest area decrease (from 0.20 ha to 0.09 ha in the period, 1951 to 1991) is also prominent which is causing the problem of maintaining sustainability. Heavy pressure on natural resources, limiting land availability, depleting soil fertility, waterlogging, salinity, alkalinity, acidity, sand drifting, soil erosion, runoff, siltation of rivers, floods, droughts, environmental deterioration and ecological disturbances are the main causes of declining sustainability. Wastelands which are categorized and classified as degraded forest lands contain badly eroded marginal and submarginal farm lands and public land owned by government agencies like railways, canal, public works, educational institutions, village panchayats etc. (Tewari 1994). The area under different category of degraded lands and the problematic soils are presented in table 1.1.

Such extensive deforestation can accelerate soil erosion, floods and land slides in hilly areas, which in turn may affect crop production, both in hilly and plain regions. Denuded wastelands increase the atmospheric temperature, loss of their water holding capacity and often cause changes in the climate. It is necessary to conserve these

resources and use them on a sustainable basis for our survival.

Table 1.1: Extent of degraded lands and other problematic soils in India.

CATEGORY	OCCURRENCE	AREA (m ha)
Area subject to serious water and wind erosion	Water erosion areas in all climatic regions specially and sub-humid and humid areas. Wind erosion areas mostly in arid regions of Gujarat, Rajasthan and Haryana	150.0
Riverain land, coastal sandy areas and high altitude and steeply sloping lands.	Coastal regions, interior mountainous regions and steep slopes in Himalaya	11.3
Salt affected lands.	Semi-arid regions of Indo-Gangetic plains and peninsular regions.	8.5
Water logged areas.	Low lying areas in high rainfall regions and irrigated areas etc.	6.0
Ravine lands	Banks of rivers in Gujarat, Rajasthan, M.P. and U.P.	4.0
Shifting cultivation	Mostly in north-eastern region.	3.0
Acid soils	Higher altitudes of Himalayas, eastern and north eastern plains and peninsular and coastal plains	25.0
Barren hill ranges on rock out crops	Distributed in hill ranges in various states	2.7

Source: Hirekerur *et al.* (1990), Mandal (1989) and Singh (1992).

Thus, while food production is being maintained, the vital supplies of firewood for rural energy needs (cooking) and fodder for livestock are at a deficit. Our existing resources can only supply up to 17% of the firewood needs and 47% of the industrial wood. This situation compels the use of crop residues for fodder and firewood and also the animal dung manure is diverted for domestic energy needs. The current demands of about 1000 M t of organic manure for profitable agriculture gets a supply of hardly one third of 170 M t produced. Most of it is diverted to house hold energy needs as dung cake. This is regarded as a serious threat to future sustainability of agriculture.

Considering the above situation, energy, plantation was emphasized by many (NCA 1976, Patil and Pathak 1977). Energy plantation is a high density plantation forestry with short and mini-rotation species of woody perennials on degraded lands, marginal agricultural lands, crop field boundaries etc. The wood of high calorific value forms a better choice as firewood since it is a renewable form of energy. Use of biomass energy has found favour over the other non-renewable forms of energy viz, coal, petroleum products etc. due to its non-polluting nature and easy to produce *in situ* by the users.

During the past 20 years research on such short rotation multipurpose tree species (MPTS) has been intensified and emphasized. There also have been efforts to work on nitrogen fixing tree species (NFTS) to fulfil the demands of agriculture. The efforts at global level to give emphasis and research thrusts on these species are credited to Nitrogen Fixing Tree Association (Hawaii) and Winrock International's MPTS Research Network (Bangkok). In such programmes interest was generated globally on many leguminous and non-leguminous tree species of which *Leucaena Leucocephala* was the prime tree species.

In the last two decades, *Leucaena Leucocephala* and its varieties from Hawaii have been imported and planted in many tropical countries for fodder, fuel, fertilizer, conservation and several other attributes. The two early monographs by National Academy of Sciences, Washington (NAS 1977, 1984) entitled **Leucaena : Promising Forage and Tree Crop for the Tropics** gave further impetus to this research.

During the 1970's and early 1980's *Leucaena leucocephala* (Lam.) de Wit. (*Leucaena*) was proclaimed as the miracle tree because of its world wide success as a long lived and highly nutritious forage tree, and its great variety of other uses. As well as forage, *Leucaena* can provide firewood, timber, human food, green manure, shade and erosion control. It is estimated to cover 2 - 5 million ha world wide (Brewbaker and

Sorenson 1990).

Leucaena has its origin in central America and the Yucatan Peninsula of Mexico, where its fodder value was recognized over 400 years ago by the Spanish conquistadors who carried *Leucaena* feed and seed on their galleons to the Philippines to feed their stock (Brewbaker *et al.* 1985). From there it has spread to most countries of the tropical world where *Leucaena* was used as a shade plant for plantation crops. Duthie (1903) opines that the plant is introduced in India and is becoming naturalized in many places.

Leucaena is a genus of family Mimosoideae with about 16 species. Its taxonomy is confused. Although all the species may have value through out the tropics, only *Leucaena leucocephala* (Lam.) de wit has been exploited extensively. *Leucaena leucocephala* has been recorded in the literature under several botanical names. The present position about their recognized subspecies, chromosome number and the origin are presented in table 1.2.

Common Names

Few countries lack their own names for *Leucaena*. Some known ones are: *guaje* in Latin America, *Subabul* earlier known as *kubabul* in India, *Ipil - Ipil* in Philippines, *Lamtoro* in Indonesia and *Yin hue whan* in China. the Hawaiians named it as *koa haole* and *Leucaena* varieties developed in Hawaii are named K8, K28, K636 etc., K for *koa*. The classical work of Brewbaker (1987) generated many versatile selections of this species, which were later introduced in many countries of the tropics.

Botany

Leucaena vary widely in leaf and tree shape. Duthie (1903) describes *Leucaena glauca* (Family Fabaceae) as a shrub or small tree with large alternate and bipinnate

Table 1.2 : Recognised species, subspecies their chromosome number and origin.

Recognized species and authorities	Recognized subspecies	Chromos-ome number	Plant height (m)	Origin
1. *L. collinsii* B&R	*collinsii* *Zacapana*	52 not known	5 - 15 6 - 15	Southern Mexico - do -
2. *L. confertiflora* Zarate ined	adenotheloidea confertiflora	- c. 112	- 3 - 5	 Central Mexico
3. *L. cuspidata* Standley	-	c. 112	3 - 6	Northern eastern Mexico
4. *L. diversifolia* (Schlecht.) Benth	*diversifolia* *stenocarpa (Urban) S. Zarate com. ined*	104 52	8 - 20 3 - 20	Vera Cruz Guatemala
5. *L. esculenta* (Moc. & Sesse ex ADC) Benth.	*esculenta* *matudae Zarate ined* *paniculata (B.&R.)* S. Zarate comb. ined	52 not known 104	12 - 20 6 - 10 4 - 20	Central Mexico south central Mexico Jalisco
6. *L. greggii* S. Watson		56	3 - 7	Nuevo Leon
7. *L. involucrata*	-	-	-	North west Mexico
8. *L. lanceolata* S. Watson	(unassigned) *lanceolata* sousae	- 52 -	- 4 - 15 -	- Chihuahua -
9. *L. lempirana*	-	-	-	Honduras
10. *L. leucocephala* (Lam.) de Wit	*(unassigned)* *leucocephala* *ixtahuacaena* *glabrata* (Rose) S. Zarate	- 104 - 104	- 3 - 8 - 8 - 20	- Argentiana Mexico and Guatemala Salvador, C. America
11. *L. multicapitulata* Schery		52	15 - 25	Costa Rica, Panama

12. *L. pulverulenta* (Schlecht.) Benth		56	5 - 15	Vera Cruz
13. *L. retusa* Benth.		56	3 - 5	Texas, Northern Mexico
14. *L. salvadorensis* Standley ex. B&R		56	10 - 22	El Salvador, Southern Honduras
15. *L. shannonii*	*shannonii* *magnifica* C. E. Hughes	52 not known	4 - 10 10 - 20	Salvador - do - Southern Mexico
16. *L. magnifica*	-	-	-	South east Guatemala
17. *L. matudae*	-	-	-	Cmerrero, Mexico
18. *L. pallida*	-	-	-	South central Mexico highlands
19. *L. pueblana*	-	-	-	North Oaxaca, Mexico
20. *L. trichandra*	-	-	-	North Nicaragua
21. *L. xspontanea*	-	-	-	-
22. *L. xmixtec*	-	triploid	-	South central Mexico
23. *L. trichodes*		52	8 - 15	S. America, Peru
24. *L. macrophylla* Benth.	*(unassigned)*	-	-	-
	macrophylla	52	4 - 12	Guerro
	istmensis	-	-	Oaxaca, Southern Mexico

Source: Colin Hughes Ed. 1993 : *Leucaena Genetic Resources*. Oxford Forestry Institute, Oxford, U.K.

Bray *et al.* (1997).

leaves, pinnae are 4 - 8 pairs, leaflets 10 - 15 pairs, 3/8 - 1/2 inches long, linear, acute memberaneous, finely downey, peduncles auxiliary, solitary or in pairs as long as the petiole bearing a dense globular head of flowers, anthers versatile. Pods 5 - 6 inches clustered in umbels, straight linear, flat, shining, many seeded. Seeds are elliptic, compressed, shining with different shades of brown colour, 3 - 4 mm wide, 6 - 8 mm

long and about 2 mm thick (Fig. 1.1, Plate 1 a & b).

Ecology

Leucaena originated in the midlands of Guatemala, El Salvador and Southern Mexico (Fig. 1.2 and 1.3). From there it spread through out the coastal low lands by pre - columbian Indians (NRC 1984). The species range from sea level to over 2000 m elevation and in areas with annual rainfall between 500 - 2000 mm. *Leucaena* are associated with soils of pH 5 - 8, and are not found on water logged soils, low saturation of phosphorus, calcium and high saturation of aluminium and high salinity limits its distribution.

The genus is considered an interbreeding complex and breeding efforts are concentrated on producing interspecific hybrids. *Leucaena leucocephala* has been crossed successfully with all other species except *L. greggii.* Over 50 species hybrids are now under study in Hawaii for growth, form, psyllid resistance, cold tolerance and fodder quality. Many hybrids have high commercial potential, notably in cooler climates and on certain acid soils where *L. leucocephala* is an economic failure.

Brewbaker *et al.* (1972) recognized different species in the genus *Leucaena.* These species have differential leaf size, flower colour, growth, ecology, distribution and other traits. Several collections in the areas of its origin have brought out the information about the existence of large variability in this genus with many races. The *subabul (L. leucocephala)* is an amphidiploid (2n = 104).

Leucaena is a tropical species requiring warm temperatures (25 - 30 ^{0}C day temperature) for optimum growth (Brewbaker *et al.* 1985). At higher latitudes and at elevated tropical latitudes growth is reduced. It is not found to be tolerant of even light frosts which cause leaf to be shed (Isarasenee *et al.* 1984). It does not thrive well under

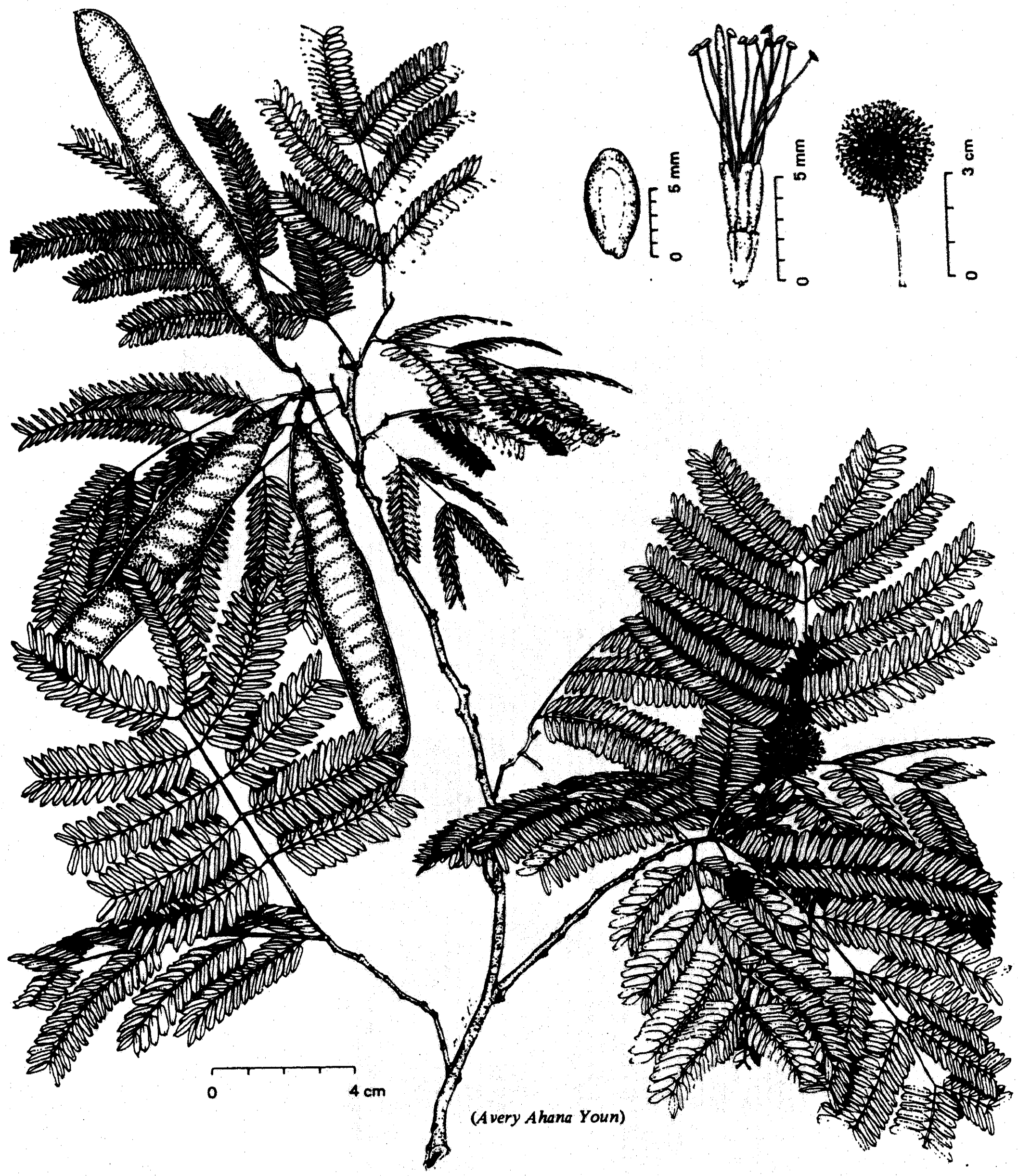

Fig. 1.1: *Leucaena leucocephala* (Lam.) De Wit (taken from NAS 1984)

A

B

Plate 1 : A) A general view of *Leucaena leucocephala* tree loaded with pods (April).
B) A close-up view of flowering branch of *Leucaena leucocephala* with flower, bud and initiating fruits (March).

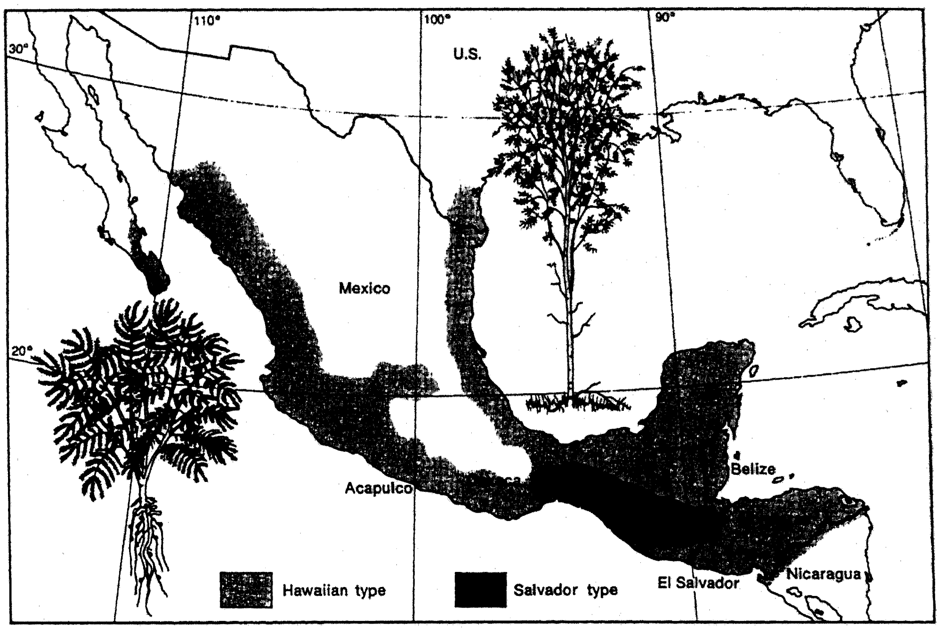

Fig. 1.2: Originating in the midlands of Guatemala, Honduras, El Salvador, and southern Mexico, *Leucaena* was spread throughout the coastal lowlands by pre-Columbian Indians. The common type is a rapidly flowering, many-branched shrub, while the giant type is a single-trunked tree that may reach 20 m in height. Today, specimens of the giant variety, which has large pods, can be found scattered throughout western Mexico, where *Leucaena* pods are a traditional food (taken from NAS 1984).

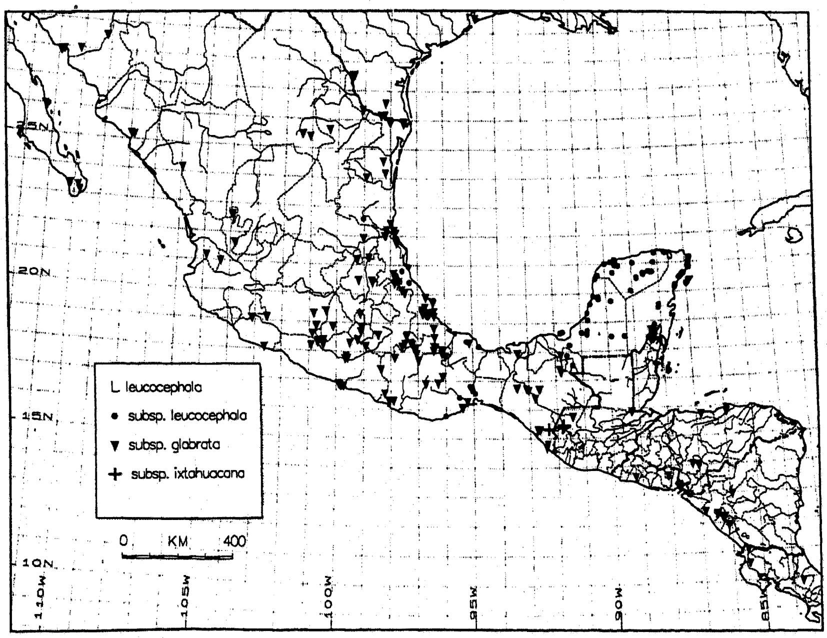

Fig. 1.3: Map of Mexico and northern Central America showing the distribution of three subspecies of *Leucaena leucocephala* (taken from Bray et al. 1997)

shading (Benjamin *et al.* 1991). Plants responded to shading by stem elongation, stem weight ratio, leaf area ratio and specific leaf area (Friend *et al.* 1988).

This tree has been studied for many of its attributes. Pathak *et al.* (1974) found that heavier seeds gave poorer germination due to hard coat. It needs scarification by sulphuric acid for 5 minutes to give more than 50 % germination (Pathak and Naugraiya 1992, Lulandala and Luther 1981). Boiling water treatment was also found to be effective. Sharma *et al.* (1994) found that pod maturity affected the germination of seed.

Leucaena is very drought tolerant even during establishment. Young seedlings have survived extended periods of dry weather (Shelton and Brewbaker 1994) and found to exhibit better drought tolerance characteristics than number of other tree legumes (Swasdiphanich 1992).

A lot of studies done on the effect of applied nutrients affecting growth, revealed that phosphorus and sulphur were the most limiting nutrients irrespective of the rhizobial innoculation, but in the absence of rhizobium the nitrogen and potassium were limiting (Relwani *et al.* 1986, Bandara and Gunasena 1988, Ezenwa and Cobbina 1991). de Lucena *et al.* 1991 found that *Leucaena* needs phosphorus for vigorous growth and nitrogen fixation. Micronutrients had also been found to exert different effects at different growth stages. Hussain *et al.* (1988) revealed that the mixture of potash and iron on addition shows maximum height and girth growth at 3 months and 12 months stages while at 9 months stage maximum growth has been found to be in potash + Vanadium mixture.

On comparing different varieties for growth Pathak and Patil (1981) reported El Salvador and Silvi - 4 to be superior over K 8 or K 28 while Chaudhary and Ahmad

(1990) found K 8 to be superior. Wider spacing improved dbh (Relwani 1982) while close spacing increased forage production (Khot *et al.* 1991, Desai *et al.* 1988). Under irrigated conditions *Leucaena* showed better growth in dry areas (Relwani *et al.* 1982, Chaudhary and Ahmad 1990).

Herbage yield was found to increase with increase in harvesting interval and cutting height (Pathak *et al.* 1980, Krishnamurthy and Mune Gowda 1983, Osman 1981 Ezenwa 1994, Sharma 1994, etc.). Pathak *et al.* (1980) found that maximum forage production was found to be in rainy season in almost all the cultivars in rainfed conditions in semi- arid region.

Sethu *et al.* (1985) and Friend *et al.* (1988) observed that the *Leucaena* varieties were superior over local types in the rate of photosynthesis. Natarahan *et al.* (1985) reported highest photosynthetic rate at the flowering stage in *L. leucocephala* variety K 8. While photosynthetic rate and transpiration have not been found to follow the trend of irradiance. It has been found that, as the temperature increases, the CO_2 assimilation rate and stomatal conductance decreased which in turn influenced positively the water use efficiency (Prasad and Rajeswar 1989). There is no significant differences found in mineral nutrients and other nutrients between the species (Gupta *et al.* 1986, Hu *et al.* 1983).

In studies on the moist river banks at Jhansi, Pathak *et al.* (1985) and Pathak and Gupta (1987 & 1991) reported an annual above ground productivity up to 74 t/ha at 5000 plants per ha density. Its biomass models were prepared by Khan and Pathak (1986, 1989) where equations based on diameter and height were evolved for best prediction of biomass from the plantations. While working on degraded lands Pathak and Gupta (1994) found that bole had direct effect in controlling the above ground biomass production. Selections S 24, S 10 and S 14 were identified as superior provenances for timber and fuelwood production over K 8 with 34, 19.5 and 3 % more biomass.

Leucaena shows pronounced coppicing ability over other fodder trees (Pecson and Brewbaker 1991 and Dutt and Jamwal 1987). It has also been found that the soil under *Leucaena* plantation exhibits increased percentage of nutrients especially N, P and K level (Jha *et al.* 1991, Girdhari Lal 1988, Weeraratna 1982).

Thus, from the foregoing it is evident that although many such studies are available but there have been no efforts at analyzing growth phases, production, energetics and the production processes along with their inter relations to suggest the contributing factors for optimizing the biomass yield on dry degraded lands. The present study attempts at characterizing the giant varieties of *Leucaena* for various growth and related parameters and their effects on biomass partitioning and energetics of the plantations.

This study aimed at finding out the functional aspects of tree growth, productivity and energy dynamics of *Leucaena leucocephala* plantation on the degraded land for its sustainability. The objectives were to :

- ► characterize the *Leucaena* giants for their tree growth, canopy architecture, phenology and associated plant processes, viz., chlorophyll and carotene content, photosynthesis, transpiration and enzymatic activities like nitrate reductase activity etc.

- ► study the dry matter production, partitioning and its energetics in different components at various growth stages and

- ► to compute the productivity and energy flow models as affected by various environmental factors.

Results of these studies are presented in the subsequent chapters and are also discussed in the light of existing scientific literature on the subject.

Chapter 2

Review of LITERATURE

2

REVIEW OF LITERATURE

2.1 Tree Growth

The growth and development in plants are complex phenomenon, encompassing a number of diverse processes. The sum total of these processes lead to extension and reproductive growth phases. These processes are more complex in woody perennial species than in the herbaceous forms. Trees grow both in length and girth through the activity of meristematic tissues. Extension growth results from bud expansion and the stem growth usually, but not always, encompasses both, growth and expansion of the internodes (Purohit 1994).

The growth of a tree as a whole is exceedingly intermittent. However, many tropical trees have been reported as growing more or less continuously, yet many are known to display it in recurrent waves (Kozlowski 1964, Purohit and Nanda 1968). The overall growth of the shoot axis consists of several sequential phases (Kramer and Kozlowski 1979). The extension growth may occur in a single flush in some species, while it may occur in two or more flushes in the other species. These growth flushes may be separated by distinct rest phases. *Salix tetrasperma* branches exhibit a single growth flush (Angrish 1983). Thapliyal *et al.* (1986) also observed a single growth flush in some temperate tree species. But in the tropical conditions many tree species have intermittent growth which occurs in two or more growth flushes during the annual growth cycle (Purohit and Nanda 1968, Kozlowski 1971, Angrish 1983). Chowdhury (1964) described the flushing pattern of Indian trees and found maximum of four flushes per year. The first recurrent growth flush of broad leaved plants occurs during the period

from February to April, second during July to September, the third and fourth, if they occur at all, during October and November and December to January respectively. Four flushes of growth per year in *Callistemon viminalis* were also reported by Purohit and Nanda (1968).

Shoot growth is mainly of two types. One is rhythmic, in which shoot has a marked endogenous periodicity of extension (Halle and Martin 1968). Romberger (1963) used episodic growth, Koriba (1958) intermittent growth and Tomlinson and Gill (1973) used articulate growth for this type of growth. The second pattern of shoot growth, in which shoot has no marked endogenous periodicity of extension. This term is found to be synonymous with ever growing (Koriba 1958) and non-articulate growth (Tomlinson and Gill 1973). Tropical trees have been found to show continuous growth due to leaf flushing in all the seasons without long periodicity.

The time of growth initiation is variable among the tree species. Temperate trees exhibit great variation among the date of growth initiation and growth cessation but the date of growth cessation has been found to be more variable than the growth initiation (Kramer 1943). Zimmerman and Brown (1971) reported that these phenomenon has also been found to be controlled by hormonal balance within the tree. In addition to the genotypic factors of tree, its growth has also been affected by environmental factors. The maximum vegetative growth has been reported in long photoperiods. Light intensity and duration has been found to affect the elongation of stem.

Growth has been found to be dependent upon season, leaf number and leaf area (Bhatt 1990). The detailed study on the growth of woody plants in relation to water was made by Rutter and Whitehead (1963), Zahner (1966) and Kaiser (1987). Extension growth seems to be very sensitive to initial water deficit due to decrease in turgor components which is responsible for the depression of cell enlargement (Lawlor 1970,

Wardlaw 1969). Hasio *et al.* (1970) reported that with very small depression in leaf water potential the extension growth decreases. Soil moisture affects the radial growth to much extent (Braekke and Kozlowski 1975).

It is observed that the growth pattern of the tree species is determined by the life span of the trunk axis meristem. Commonly the trunk is monopodial in nature with a potential of indefinite growth. Loss of apical meristem changes the growth pattern of the tree and leads to sympodial growth (Purohit 1994). Kramer and Kozlowski (1979) reported that there is a pronounced effect of age of the tree on its growth, The trees of the border rows have been found to show higher growth rate than that of the trees in the forest communities.

The growth of roots has been reported to be continuous. The growth of root begins earlier than that of shoot in spring and active root growth extends several weeks after the shoot growth is ceased and small amount of intermittent root growth has been reported in the winter (Randel and Nobel 1991). Roots are the systems of unlimited growth from apical meristem. A single root may contain all the phases from newly born meristematic cells through phases bearing active root hairs, phases in which the cortex has decomposed and phases in which little remains except a conducting strand (Harper *et al.* 1991).

The activity of root system is closely related to the soil moisture and its temperature. High temperature in the upper soil horizons during the summer months is also a factor limiting root growth (Fernandez and Caldwell 1975, Jorden and Nobel 1984). Root / shoot ratio is found to be high in low water conditions and high at soil temperature below and above the optimal (Davidson 1969, Radin and Bazlevich 1967). At low temperature the photosynthates are diverted to roots resulting in high root / shoot ratio in many plants (Beever and Cooper 1964). Singh *et al.* (1982) studied the dry

matter production and growth performance in only one year old seedlings of *Diospyros montana* and *Buchnania latifolia.* The dry matter production in plant parts as well as the whole seedlings increases with the age and attains a peak value followed by a reduction due to litter fall and other losses. The periodic changes in productivity of the plant indicates that highest value is obtained at the age of one month and lowest at 12 months age in both the species the maximum elongation of root and stem, is measured in rainy season and minimum in the summer season.

2.2 Phenology

Phenology is an important function of forest ecosystem that relates the growth habit of the species with the physical environment. Lieth (1970) defined phenology as the sequence of calendar of events in the life history of plants. In more simpler way, it is the study of growth of buds, leaf fall and leafing out, anthesis, fruiting and seed dispersal in relation to months, seasons or years.

Phenological patterns have been found to differ with species, genetic variability within a species, plant age, site conditions such as soil type and incidence of fire, climatic factors such as rainfall, its distribution, air humidity and temperature; and biotic factors such as pollution, browsing and insect attacks (Breman and Kessler 1995). In semi-arid regions climatic factors and site conditions seem most important. The less these factors vary; the more predictable are phenological patterns.

Phenological patterns of different vegetation types are available such as for tundra (Sorensen 1941, Mooney and Billing 1961), Rocky Mountains (Holway 1965) and rock valley in the northern Mojave Desert (Shreve 1942) in North America. Lieth (1970-71) studied the phenological events in relation to productivity and ecosystem

function. A lot of study has been done mainly on tropical tree species (Koelmeyer 1959, Lieth and Radford 1971, Medway 1972, Daubenmire 1972, Frankie *et al.* 1974, Croat 1975, Putz 1979 etc.). In India such type of studies have been done from time to time on different regions. Boojh and Ramakrishnan (1981) and Shukla and Ramakrishnan (1982) studied the phenology of some forests in north eastern India. Ralhan *et al.* (1985 a,b) have given phenological characters of some trees and shrubs of Kumaun Himalaya. Sundriyal *et. al.* (1987) studied the phenology of alpine plants. Bisht *et al.* (1986) studied the phenological pattern of evergreen vs. deciduous trees of central Himalaya.

Woody species are generally classified into two phenological categories, evergreen and deciduous, a classification reflecting different dry season survival strategies (Breman and Kessler 1995). Whitmore (1984) defined four types of leafing periodicity in the Asian tropics: evergrowing, manifold, intermittent and deciduous other terminologies used by Kikuzawa (1983) are succeeding type, intermediate type and flush type. Evergreen species have green leaves throughout the year. New leaves replace old ones before older leaves are shed. Semi evergreen species are almost without green leaves for two months at the most. Deciduous species shed all leaves and have none for at least two months. Although deciduous species grow more rapidly under optimum conditions, evergreen species are more resistant to stress and better adapted to low soil fertility (Stuart Chapin 1980, Menaut 1983).

Based on leaf production patterns, trees are classified into four classes (Koriba 1958) i.e. evergrowing trees which produce leaves continuously, trees which produce leaves intermittently; trees which exhibit different growth rhythms in different parts; and lastly the deciduous trees. In some species leaves are formed only in one flush e.g. *Quercus, Aesculus* and *Litsea*. In these taxa the shoots are fully performed in winter bud and the extension growth is limited to the expansion of the predetermined components

of the bud in summer. In other species the shoots are not fully performed in winter bud, therefore, leaves are produced in succession. In temperate and tropical tree species the rhythmic growth is mainly demonstrated by the leaf-flushing or bud burst (Kramer 1943).

While studying the phenology of some temperate woody species Sundriyal (1990) reported that during December - February many species shed their leaves. Buds have been found to remain dormant throughout winters, generally up to February. As the temperature rises the dormancy breaks , flushing and leaf production occurs up to May - June and its cessation was found from July to September. For most of the species, flower bud formation is simultaneous to the leaf bud formation.

On comparing the phenology of the evergreen and deciduous trees of central Himalaya, Bhist *et al* . (1986) reported that the buds were dormant through out the winter and bud burst started during February. Leaf flushing was rapid till June. Flowering and fruit formation of deciduous species was found in March but in evergreen species it was in April. It was also found to be same in fruit maturation and seed dispersal. Deciduous species are found to bear mature fruits a month ahead than their evergreen counterparts.

Leaf sprouting and shedding is more regular and predictable feature. Flushing and leaf production towards the end of dry season and before rains is well reported in literature (Boaler 1966, Frankie *et al.* 1974, Shukla and Ramakrishnan 1982). This can be attributed to the triggering effect of the rising temperature (Walter 1968). Increase in day length can induce flushing (Njoku 1964). Sundriyal (1990) found that some species exhibit winter dry season leaf fall and dry season flushing. It can be correlated to small seasonality in temperature and large seasonality in moisture regime (Jackson 1978). Walker (1980) predicted that initial flush of leaves and twigs is mainly due to

reallocation of stored material from the previous season. Ne'eman (1993) compared four populations of tree species for leaf flushing and found different phenological patterns and he attributed that it is due to genotypic origin.

Plants belonging to the same population do not always have the same phenological flowering pattern because of the habitat and the microclimate, thus, creating complex gene - environment interactions (Jose 1993). Variations among individuals in flowering dates determines the degree of flowering synchrony of a plant species (Bawa 1983). The phenological pattern of flowering of any plant species can be characterised by its time of occurrence, duration and synchrony (Rathcke and Lacey 1985). Maximum flowering before rainy season can be ascribed to climatic conditions. Similar reports are available for some rain forests (Richards 1952, Medway 1972) but such seasonality was not recorded in Malayasian and Columbian forests (Putz 1979, Hilty 1980). It is reported that moisture, temperature and photoperiod are responsible for flowering (Seghieri 1990, Njoku 1963 and Opler *et al.* 1976). One degree variation in latitude from south to north may delay flowering upto 4 weeks (Randhawa 1956).

Fruiting is less predictable; it requires specific combination of rainfall, temperature and photoperiod which are rare for some species in semi-arid zones (Davies 1976). Maximum food production coincides with rainy season (Sundriyal 1990). Fruit development is determined by the precipitation pattern (Frankie *et al.* 1974). Deciduous species showed earlier seed maturation and dispersal than evergreen species. This behaviour of certain species can be considered as an escape from seed predation on time basis (Ashton 1969, Medway 1972, Janzen 1978 and Boojh and Ramakrishnan 1981).

2.3 Leaf Production

In temperate trees the flushing of leaves is associated with increase in temperature. However, controlled environmental studies have shown that bud-break in some tropical trees is closely influenced by the day length (Nanda and Purohit 1966, Longman 1966). Rainfall can act as a triggering agent for flushing (Njoku 1964), because in evergrowing forests, flushing frequently occures in dry season before raining (Longman and Jenik 1974).

Leaf habit is a concept of population of leaves on a tree at a time. It is well known that different leaf habit patterns are observed in the same climatic region. Therefore leaf habit is not governed solely by the climatic conditions but is the outcome of evolution . It is observed that the evergreen broad leaf trees are usually found on ridges and higher slopes while deciduous trees occupy valleys, with relatively higher moisture. The advantages of the evergreen habit is that it obviates the necessity of spending food resources on a wholly new photosynthetic apparatus every year. However, evergreen species have mostly lower photosynthetic rates than the deciduous species. It is attributed to the longer functional life of individual leaves in evergreen species (Purohit 1994). The older leaves may also act as winter food storage organs, since lipids and proteins are mobilised and translocated from old to new leaves during the growing season (Hadley and Bliss 1964). As leaves are born only slowly in the winter, but those that are produced live long. Leaves are produced more rapidly in the summer but have a short time to live (Harper 1989). The dimension of the mature leaf lamina has also been found to be affected by increased light intensity and temperature (Kozlowski and Clausen 1966). Leaf thickness is found to be increased with increasing light intensity. As the temperature increases the fresh and dry weight also increases.

Growth rate has been found to be closely related with shoot elongation and is often quite rapid during the middle part of the growing season (Longman and Jenik 1974). The monopodial tree species show rhythmic growth pattern, usually have fast leaf turn over rate and are either evergreen or semi deciduous. Those with only one growth flush per year and monopodial are also evergreen or semi-deciduous. However, determinate tree species are invariably deciduous. It seems that leaf longevity is closely correlated to the rate of growth. Negative correlation has also been found between shoot extension growth and leaf retention time (Kohyama 1980).

The growth of leaf may be divided into two stages, each affected differently by environment. In the first stage, when initiation and emergence of the lamina depends on the growth of the plant as a whole, an increase in light intensity or temperature leading to increased plant growth gave similar increases in the growth of developing leaves. The second stage occurs when the lamina grows out of the protecting sheaths of earlier leaves, becomes directly exposed to the light environment, and begins photosynthesis. The morphogenetic effects of light intensity, temperature and photoperiod during this period are not necessarily the same as a whole.

The dimension of the mature leaf lamina has also been found to be affected by increased light intensity and temperature (Kozlowski and Clausen 1966). Leaf thickness is found to be increased with increasing light intensity. As the temperature increases the fresh and dry weight also increase. Pokhrial *et al.* (1989) have reported in *Populus deltoides* that maximum number of leaves per plant were observed in the month of April and minimum in July, whereas maximum number of leaves were shed in the month of November.

Flushing and leaf production towards the end of the dry season and before rains is well reported in literature (Boaler 1966, Frankie *et al.* 1974, Shukla and

Ramakrishnan 1982). This can be attributed to the triggering effect of the rising temperature (Walter 1968). Increase in day tength can induce flushing (Njoku 1964). Joshi *et al.* (1990) reported the turnover values of the leaves during different seasons in different regions indicated that the rates of replacement of above ground parts were always minimum in summer and maximum in winter.

Lodhiyal *et al.* (1992) have reported that the contribution of leaves to above-ground biomass was 7.6-11.5%, which exceeds the higher side of the range, 2.6-9.3%, reported for certain temperate and tropical forests of World (Harada *et al.* 1972; Johnson and Risser 1974; Whittaker 1975; Singh 1979; Negi *et al.* 1983; Rawat 1983; Rana *et al.* 1989) and 3.0-10.0% reported for Populus deltoides (Raizada and Srivastava 1989).

The variation in leaf production and leaf expansion rates at comparable age, were more season dependent. Variation in specific leaf weight (SLW) was dependent more on growing season than on the age of the plants (Ledig et al. 1974), however the effect of age was more prominent on leaf weight ratio (LWR) than on leaf area ratio (LAR). The SLW is higher at lower temperature (Peet *et al.* 1977), and lower at higher temperature (Raper *et al.* 1971).

2.4 Tree Canopy Structure

Plant canopy structure is the spatial arrangement of the above ground organs of the plants in a plant community (Campbell and Norman 1989). In semiarid regions, woody plant canopy cover is considered a useful indicator of the distribution of woody plants and their influence on the plant production factors and interactions between woody plants and herbs (Breman and Kessler 1995).

According to Kramer and Kozlowski (1960), a tree is a complex biochemical factory which starts from a seed and literally builds itself. The two main parts of tree are crown and trunk. Theoretical model for tree structure has been proposed by Shinozaki *et al.* (1964 a, b) who interpreted plants as being constructed of vertical and horizontal fascicular pipes with each pipe responsible for linking a perticular piece of root system to a portion of the leaf canopy. Also there are those who counted the plant form as an almost passive response to evolutionary pressure exerted by herbivory, predation and disease (Harper 1984). Bell (1984) revealed that plant form is the result of birth, aging and death of plant meristems. For a plant containing both vegetative and flowering meristems, over discrete periods of time a vegetative meristem can remain as such or can grow to produce copies of itself (Porter 1983 a, Van Groendael 1985).

Besides its functional features canopy shape has a taxonomic role in distinguishing one species from the other (Porter 1989). According to Mitchell (1974) on the basis of floral morphology and leaf shape one community of trees can easily be identified. Differences in whole plant form are caused by the leaf and other plant parts being held in certain positions by branches of various lengths and at different angles. On that basis Halle *et al.* (1978) categorized tropical trees into 23 architectural types or models. These characters are in pairs as shoots being monopodial or sympodial, orthotropic or plagiotropic, pleonanthic or hapaxanthic, basitonically or acrotonically branching, whether growth is rhythmic or continuous, construction is modular or non-modular, branches axillary or dichotomous, branches short lived or long lived, axis being homogenous or heterogenous. Several models have been given by many workers as by Mcclure (1966) and Troll's model (Troll 1937). The lower most branch is the most significant feature of the tree. It has been found that lower most branch sheds progressively, so the crown gets gradually displaced vertically (Oldeman 1974).

Ross (1981) recommended that for the complete and accurate description of canopy, its specification of the position, size and orientation of each of the elements on the surface was necessary. Description of plant canopies at individual level is very important. It should include, parameters of typical length, width, area, specific dry mass, specific water content etc. In addition to this, it is useful to record stem diameter at one or two locations, total number of leaves per plant, number of nodules per plant and the spatial distribution of organs within the plant outline.

The leaf orientation significantly affects the canopy structure. De wit (1960) divided plant canopies into several types based on distribution of leaf angles within the stem. The extreme forms are the planophile canopy in which horizontal leaves are more frequent and the erectophile canopy in which vertical leaves predominate. Erectophile canopy has been found to be more productive than the planophile (Monsi *et al.* 1973).

The crown structure in tropical trees appears uniquely adapted to the peculiar radiation environment (Dohrenwend 1969) and bear relationship to the moisture regime of the ecosystem. Growth rate is often found to be proportional to the amount of the radiation intercepted by the canopy (Russel *et al.* 1989). Temperature is also found to affect the tree development (Squire *et al.* 1984, Mohamed *et al.* 1988). Shortage of water has been shown to reduce photosynthetic rate. This results in stomatal closure and premature senescence of the leaves (Legg *et al.* 1979, Hughes *et al.* 1987).

Deficiency of nutrients also affects the development and structure of the canopy. Nitrogen deficiency may cause stomatal closure at higher water potentials (Radin and Ackerson 1981) or a reduction in water uptake by increased root resistance (Radin and Boyre 1982) and a consequent reduction in transpiration (Shimshi 1970 a, b; Shimasi and Kafkafi 1978) which will alter the energy balance of the canopy and hence its temperature.

Despite the detailed work on canopy structure, a little work has been done on Indian tree stands specially in the degraded lands. The aim of this study is to know the increase or decrease in canopy cover in different seasons and the ratio of the leaf to stem in different months.

2.5 Growth and Photosynthesis

The rate of photosynthetic CO_2 uptake is an important component of growth (Ledig and Botkin 1974). Analysis of seasonal pattern of CO_2 exchange of different plant parts may also be useful in constructing physiological models to explain tree growth (Ledig 1969). Because of the potential utility of growth components in breeding, it is desirable to quantify genotypic and environmental variation in photosynthesis.

Carbon balance model has been used to describe plant growth in relation to light and CO_2 levels (Monteith 1965) and experiments under controlled environmental conditions have established a relationship between light and CO_2 exchange (Mc Cree and Troughton 1966 a & b). Ledig *et al* (1976) concluded gas exchange studies simultaneously with dry weight harvests to study episodic growth in Pitch Pine seedlings and reported that spurts of growth could be forecasted by high respiration rates, which probably are required for synthesis of high energy compounds prior to cell elongation and cell formation.

Some investigators have found either a weak correlation or none at all between the measurements of photosynthesis and growth. The best correlation was reported by Huber and Polster (1955) for some of the clones of Poplar (*Populus* L.) which vary in their growth. Frequently there is negative correlation between seedling size and unit photosynthesis (Ledig and Perry 1967). Ledig *et al.* (1976) proposed that dry matter

production should be related to the total CO_2 fixed during longer period so that the necessary stable conditions exists. Greater size i.e. more leaves and greater depths of the seedling crown results in self shading or a reduction in the average light intensity reaching the other leaves (Kramer and Clark 1947). This implies that seedlings with high photosynthetic rate and thus potentially fast growing, experience self shading sooner than the seedlings with low photosynthetic rates, as a result, their relative growth rate declines rapidly.

2.6 Photosynthesis

Photosynthesis can be assigned as a possible annual renewable resource for material and energy. Photosynthetic process exhibits enough plasticity so that they could get adjusted easily to changing environmental conditions in any habitat during seasonal growth.(Mooney *et al.* 1964 Mooney and West 1964). The potential to grow over a gradient of habitats may also be affected by photosynthetic plasticity. About 85-90% of the dry matter production of plants is carbonaceous matter derived from photosynthesis i.e. the light dependent reduction of $C0_2$. Carbon balance mode has been used to describe plant growth in relation to light and CO_2 level (Monteith 1965, De Wit 1965).

Photosynthetic process is followed by series of complex reactions. The product of photosyntheis are consumed through respiration. Rates of these processes are influenced by light, temperature, moisture, food supplies etc. and these conditions are largely determined by the season (Gopal 1972).

The general activity of photosynthesis declines at the end of the season due to decrease in light intensity, photoperiod, temperature, leaf area and aging of leaves. The net assimilation rate of first year loblolly pine seedling has been found to decline with age (Ledig and Parry 1967). Primary leaves exhibits higher rates of CO_2 uptake than

secondary leaves, which declines with age (Bourdeau and Morgen 1959, Wright 1970). During winter season photosynthesis is found to decline, which gradually increases in early spring. The physiological depression has been considered a type of true dormancy (Tranquillini, 1957 Bamberg *et al.* 1967). In contrast to this, Mooney *et al.* 1966) showed that plants of *Pinus aristata* have stable CO_2 gas exchange throughout the total growing season. Nunes *et al.* (1992) reported that rates of photosynthesis and leaf conductance of the leaves of carob tree (*Ceratonia siliqua* L.) growing in natural conditions were measured during the course of the seasons to define the effects of the main climatic factors limiting growth in the season. Temperature during the winter and water in the summer were observed to be highly limiting factors. Vandana and Bhatt (1996) reported that the photosynthetic rate (Pn) in *Sesbania sesban* and *S. grandiflora* was maximum in rainy season, which declined in autumn and reached the minimum in summer months.

The influence of day length on photosynthetic capacity of stone pine was studied by Bamberg *et al.* (1967). Rates of photosynthesis increased as radient energy increases but becomes depressed in most species at high radient energy with high temperature. Net photosynthesis per unit area has been observed to increase from low to medium light intensity and then decreased at the highest intensity (Chabot and Chabot 1977). Photosynthetic rates under different light intensities strongly depended on leaf to air temperature differences (Purohit 1994). High land tree species seem to make more efficient use of high light intensity as compared to the lowland species (Mooney and Billings, 1961, Hiesey *et al.* 1971).

A linear relationship exists between net photosynthesis and total conductivity for CO_2 between out side air and the intercellular spaces (Louwerse and Zweeride 1977). The values of light saturating intensity incresed with increasing CO_2 concentration

(Wilson and Cooper 1969). At high CO_2 concentration, plants grown in strong light have higher rates of photosynthesis than those grow in a weak light (Wilson and Cooper 1969).

The under temperature tree species were found to have relatively higher rate of photosyntheis than that of over temperature species (Purohit and Dhyani 1988, Slatyer 1977, Bjorkman et al. 1974) . Seasonally, temperature change has limiting effects on photosynthesis and respiration of shoot and root (Drew and Ledig 1981). The seasonal fluctuation in net photosynthesis is strongly correlated with progressive shifts in temperature response or acclimation (Strain et al. 1976). The alpine and sub-alpine plants show maximum photosynthesis at lower temperatures (Mooney et al. 1964). It is well known that radiation flux density has an effect on the position of the temperature optimum (Scott and Menalda 1972).

The photosynthetic system of a plant is quite well adapted to the temperature-regime of their habitat (Pisek *et al.* 1969). The desert plant also showed a high photosynthetic capacity even at high leaf temperature (Schulze *et al.* 1972 b; Bjorkman *et al.* 1972). Photosynthetic adaption and acclimation to low and high temperature may be regarded as two apparently separate phenomena. The superior performance at low temperature of cold adapted plants is attributable to an increased photosynthetic capacity. Photosynthesis is one of the most heat sensitive aspect of growth. Excessively high temperature causes an irreversible inactivation of photosynthesis.

Mooney *et al.* (1964) compared the photosynthesis of various plants at 300 and 200 ul I^{-1} CO_2. He observed that photosynthesis at 200 ul l^{-1} was on an average 40% less than in 300 ul l^{-1} CO_2. At normal CO_2 concentration (0.03%) photosynthesis is almost independent of leaf temperature, while at higher concentration the rate is strongly influenced by temperature so that light saturation was not reached at the highest

temperature (Gaastra 1959).

The photosynthesis of higher plants is strongly inhibited by the oxygen concentration of normal air (Bjorkman 1966, Tregunna *et al.* 1966). It is also observed that the rate of CO_2 uptake of many plants is enhanced when the oxygen concentration surrounding the leaf is reduced from 21% to a lower level. The compensation point for photosynthesis has a relatively high value in some plants in 21% O_2. However, in some plant species the CO_2 compensation point is close to zero even in 21% O_2 (Bjorkman *et al.* 1968). Several workers have shown that the exhibition effect of O_2 on light saturated photosynthesis decreases when the ambient CO_2 concentration is increased and even disappear entirely at sufficiently high CO_2 concentration (Fock *et al.* 1969, Jolliffe and Tregunna 1968).

When the leaves have low water potentials the rate of photosynthesis declines. The loss of photosynthetic ability is generally attributed to the closure of stomata of the leaves (Hasio 1973). The closure of stomata hinders the diffusion of CO_2 into the chloroplast and brings about a loss in the photosynthetic ability (Brix 1962).

The photosynthetic rates are also influenced by soil moisture. In seedlings of timberline species, *Larix decidua, Picea abies* and *Pinus cembra* started a gradual decline in photosynthesis as soon as soil water potential decreased to between - 0.4 bar (pine) and -3.5 bar (Larch) (Havranek and Beneck 1978, Han and Kakubari 1996). High wind speed in the range of 0 - 20 ms^{-1} declines the rate of photosynthesis (Tranquillini 1969). Szarek and Woodhouse (1976) reported that the photosynthetic rate is mainly affected by leaf water potential.

There are many reports suggesting that photosynthetic rates depressed due to the reduced chlorophyll concentration (Heath 1969, Sestak *et al.* 1971). But in many natural

communities the normal chlorophyll content of leaves is adequate to absorb the available photosynthetic flux (Anderson 1967) and chlorophyll contents are likely to adjust to the flux available (Rabinowitch 1951). Photosynthetic rate per unit leaf area changes with leaf age and with ontogeny (Sestak 1981).

2.7 Stomatal Conductance

The leaf conductance can be partitioned into components of the cuticular and the stomatal pathway, i.e., boundary layer, cuticle stomatal anti-chamber, stomatal pore, sub stomatal cavity etc. (Milthrope 1961, Jarvis 1971). Gaastra (1959) pointed out that CO_2 uptake depends upon both stomatal conductance and a number of biochemical and biophysical variables. The boundary layer conductance of leaves depends on the size of the leaf and wind speed (Grace *et al.* 1980). The stomatal conductance has been found to decrease with increasing altitude. Bhatt *et al* (1994) have reported that as the PAR and atmospheric temperature decreases, the stomatal conductance also decreases and they observed the lowest stomatal conductance at 1600 hours. Boundary conductance was found to be maximum around evening hours and minimum around morning hours (Grace *et al.* 1980).

The boundary layer conductance of forest canopies is typically in the range of 100-300 mm s^{-1} because of the height of the trees and much rough surface (Rutter 1968) and because of the higher wind speed, which is usually more than 0.5 m s^{-1} at the top of the canopy. Jarvis *et al.* (1976) have reported that the maximum canopy conductance of Sitka and Norway Spruce forest canopies is about 20 mm s^{-1} and for Scot pine, lodge pole pine and Douglas fir, some what less than 10 mm s^{-1}. The largest value of canopy conductance is probably about 50 mm s^{-1} in some field crops. Stomatal conductance is found to increase linearly with light intensity (Downes 1970) and decrease with

increasing temperature (Heath and Orchard 1957, Lange *et al.* 1969). Ambient humidity has been found to affect indirectly on the stomatal conductance through its effect on transpiration and leaf water status (Taylor 1974). Decreasing PAR and AT adversely affects the relative humidity, stomatal conductance and therefore, water vapour exchange decreased (Bhatt *et al.* 1994). Leaf temperature is also found to play important role by determining the out going reradiation flux and indirectly, through its effect on saturation vapour pressure (Gates 1980).

The study of stomatal conductance in controlled environment can be done best because in natural environment it is influenced by various factors as interactions between the responses, variability of the natural environment, time response in species with amphistomatous leaves and endogenous rhythms. The conductance of a leaf varies with age, position on the plant and the position in the canopy, as well as upon the season, the time of the day and recent and the current weather. The conductance of the canopy is the sum total of the conductance of all the individual leaves in the canopy.

2.8 Carboxylation Efficiency

The ratio of net photosynthesis (PN) and internal CO_2 concentration (CINT) represents carboxylation efficiency (Farquhar and Sharkey 1984). It is a measurement of availability of primary substrate for photosynthesis and a necessary parameter in partitioning between biochemical and diffusion factors in photosynthesis (Field *et al.* 1989).

PN/CINT ratio is found to depend upon the available PAR, it decreases as the PAR decreases (Bhatt *et al.* 1994). High light synthesis during growth resulted in the increase of carboxylation activity (Bowes *et al.* 1972). Its higher level was recorded in

rainy season which gradually decreased in winter and reached minimum in summer months (Farquhar and Sharkey 1984). Mature leaves have higher PN / INCO2 concentration throughout the day than young and old leaves (Siffel *et al.* 1993). It is found to increase with decreasing water supply (Briggs *et al.* 1986, Palta 1983, Jonson *et al.* 1987). As the net photosynthetic rate increases, the carboxylation efficiency also increases (Dejong *et al.* 1984). This is strongly correlated to stomatal conductance which ultimately influences the CO_2 assimilation and economy coefficient. Nitrogen fertilization is also found to increase the carboxylation efficiency (Mebrahtu and Hanover 1991).

2.9 Transpiration

Transpiration plays important role in maintaining plant water relations because it produces the energy gradient which causes the movement of water into and through plants. Environmental factors such as, temperature, light intensity, wind velocity, relative humidity, soil moisture and resistance to water movement, leaf area and leaf structure have been found to exert pronounced effect on the process of transpiration (Jung and Larson 1972, Halle and Bjorkman 1975) and in turn in whole physiology of plants. The adaptation and ability to survival of plants within a given environment depends upon the extent of their interaction with the surroundings through the phenomenon such as transpiration, light absorption and energy exchange. The water vapour exchange rate affects the energy budget and temperature of leaf and consequently this not only has a bearing on the physiology of the whole plant (Gates 1975) but also influence the surroundings (Ludlow 1987).

Leaf temperature directly determines the out going radiation flux and in turn water vapour exchange rate (Halle and Bjorkman 1975, Gates 1980). For leaves with an

adequate water supply, transpiration depends upon the sum of the diffusion resistances in the external air and the stomata (Gaastra 1959).

PAR adversely affects the relative humidity, stomatal and diffusion resistances and therefore, transfer of water vapour is increased (Nobel 1977). The rate of transpiration and water content of leaves have an inverse relationship with each other and mainly governed by the relative humidity and temperature. The extent of temperature variation in leaves is species dependent (Yarwood 1961, Lange 1975). Transpiration increased with increase in air temperature and PAR in summer and decreased in winter as reported by Haseba *et al* (1967) in *Cetrus*, Bhatt (1990) in *Prunus, Celtis* and *Grewia* and Vandana and Bhatt (1996) in *Sesbania.* Loss of water vapour exerts pronounced effect on the plant growth and productivity (Grace *et al.* 1981). The extent of the rate of water loss in subtropical timberline broad leaved evergreen and deciduous trees revealed that the rate of transpiration were higher in deciduous as compared to evergreen trees (Dhyani *et al.* 1988, Purohit 1994). Transpiration is directly proportional to the leaf area and the water vapour gradient between the air and the leaf surfaces. It is inversely proportional to the canopy resistance, encompassing stomatal, cuticular and boundary layer resistance.

It has also been found that as the CO_2 concentration of environment increases, mesophyll resistance decreases but the stomatal resistance increases which results in a significant reduction in transpiration (Ku *et al.* 1977).

Increasing temperature may result in further opening of stomata (Schulz *et al.* 1972). This causes increase in the rate of transpiration. On the other side, low temperature causes freezing of the guard cells resulting in the stomatal closure and in turn the stopage of the process of transpiration (Drew and Fritts 1972). Indirectly, low root temperatures may affect stomata by inhibiting water uptake, resulting in water

deficit within the leaves and depression in transpiration (Bababola *et al.* 1968, Havranek 1972).

Some selected species of semiarid regions were evaluated on the basis of physical and physiological parameters like transpiration rate, resistance for water vapour transfer, exchange less water vapour as compared and energy exchange (Bhatt and Misra 1989). The trees with high diffusion and stomatal resistance for water vapour transfer, exchange less water vapour as compared to those trees having a low resistance. The leaf energy balance sheet of these trees indicated that most of the energy that was absorbed was lost by re-radiation and this resulted in a negative lower flow of the convectional energy, thereby indicating that most of the trees would be able to survive in an environment at a high thermal load.

Dhyani *et al.* (1986) revealed that there are two classes in evergreen as well as deciduous trees. Those where the leaf temperatures remains lower than the air temperature during most of the time of the day are under temperature and where the leaf temperatures are higher than the air temperature are over temperature species. The under temperature evergreen species have been found to have relatively higher rate of transpiration than their over temperature counterparts. This trend was just opposite to the deciduous species (Purohit 1994).

2.10 Water Use Efficiency

Production potential of any grassland community or forest land are directly related to water use efficiency of dominant species and are important functional properties of the ecosystem (Rao *et al.* 1984). The water requirement of any plant depends upon the stage of growth and it gives them ability to utilize water efficiently

and avoid the damaging effects of water stress.

The water potential is an important property in plant water relations. Water loss affects the energy budget of the leaves and decrease leaf temperature and thus may prevent leaf tissues from over heating (Gates 1976). Woody perennials of arid conditions bear leaves only when the water supply is adequate for transpiration and at the onset of prolonged drought. The leaves of some arid zone species have a number of characteristics that are adaptive to hot dry environment. Steeply angled leaves reduce mid day solar interception. During the hot periods of the year, the leaves substantially reduce their absorbance of incident radiation by changing their moisture. At these times the light intensity required for saturation of photosynthesis is low and reduction in the radiation absorbed by the leaves therefore, results in a greater water use efficiency (Mooney *et al.* 1977). Water loss is reduced dramatically by leaf abscission. The leaf water relations also influences the stomatal behaviour and rate of transpiration and photosynthesis in some plants (Yemm and Willis 1954, Willis *et al.* 1963). It is to be assumed that the reduction in plant water content reduces the net photosynthesis (Slatyer 1967). Water use efficiency is the amount of carbon fixed per unit of water used. PN / TR ratio which indicates the water use efficiency (means the number of molecules of CO_2 fixed per molecule of water transpired) also depends upon the season (Bhatt 1989).

Singh and Joshi (1979) worked out the relationship between annual rainfall and water use efficiency for some tropical grasslands and forests and reported that the water use efficiency declined simultaneously with increasing rainfall. During vegetative phase plants are found to show higher water use efficiency which gets reduced considerably with maturity (Rao *et al.* 1984). It has been found that as the temperature increases the water use efficiency decreases due to decrease in CO_2 assimilation rate and stomatal conductance (Prasad and Rajeswar 1989). Vandana and Bhatt (1996) reported minimum water use efficiency in *S. sesban* and *S. grandiflora* during the summer months.

The water use efficiency has been found to be different in different arid conditions in C3, C4 and CAM plants (Neals *et al.* 1968). CAM plants with improved water use efficiency or their ability to improve water balance can be more productive and of better competitors than the less efficient plants. The water use efficiency of under temperature evergreen trees was found to be higher than that of over temperature ever green tree species (Purohit 1994).

2.11 Chlorophyll and Carotenoid Content

Quantitative estimation of the chlorophyll content is one of the important parameters of structural aspects of the ecosystem and may be considered as an index of primary productivity in the ecosystem (Ovington and Lawrence 1967, Redmann 1975). Chlorophyll deserved special attention because it is the light absorbing pigment in the photosynthetic process. Carotenoides function as accessory pigments in photosynthesis and may also protect chlorophyll from irreversible photooxidation (Naidu and Swamy 1996). Since it is actual place of photosynthetic activity, it is important to calculate the pigment of standing crop in any plant community. The total chlorophyll in the whole plant community is more uniform than individual plants or plant parts (Gessner 1949, Bray 1960). A number of studies have reported on the total chlorophyll and production of plant communities in different climatic regions of the world (Bray 1960, Bougham 1960, Golley 1965, Tieszen and Johnson 1968, Billore and Mall 1976, Misra and Misra 1981 etc.).

Total chlorophyll and carotenoid content were more in the shade grown plants. On the other hand the chl a / chl b is found to be lower in the shade grown plants as compared to the sun plants (Naidu and Swamy 1993). Shade plants show higher relative

content of chl b than chl a (Egle 1960, Goodchild *et al.* 1972). The decrease in chl a / b ratio was usually accompanied by an increase in chl b and specific leaf weight (SLW) which shows the shade adaptive features of plants as reported by Bhatt and Sinha (1990).

Evans (1993) worked out that photosynthetic capacity and chlorophyll content of leaf which declined exponentially down through the canopy. As the sprouting starts all the plants exhibit higher chlorophyll a and b content. Naidu and Swamy (1996) while estimating the leaf chlorophyll and carotenoid contents at monthly intervals in deciduous tree species revealed that all the species have minimum carotenoid content during winter and maximum chlorophyll content during summer. Carotenoid and chlorophyll content showed seasonal variations. Higher a/b ratios were reported for most of the temperate communities (Bray 1960, Bliss 1966). It can also be said as higher the light intensity greater the a/b ratio. Low ratios are the characteristics of the plants from low light intensities. A positive relation has been found between the chlorophyll content and both height and dry matter content (Mall *et al.* 1973). In other words the height and dry weight both are the functions of chlorophyll. Total chlorophyll content can be considered as one of the physiological criteria when selecting the species or varieties for higher productivity (Paliwal and Muthuchelian 1988).

2.12 Nitrate Reductase Activity (NRA)

Nitrate Reductase is one of the most important regulatory enzyme associated with the process of nitrate assimilation and plant growth. Considerable work has been done on cereals and lugumes to emphasize the role of nitrate reductase in yield (Johnson *et al.* 1976, Migueal 1981, Singh *et al.* 1994). Its activity is well correlated with protein content and organic nitrogen of nitrate supplied tissues (Srivastava 1980, Beevers and Hageman 1969).

Nitrate reductase activity occurs in the roots and aerial parts of most plants. The distribution of this activity is mainly correlated with the availability of nitrate in each organ, a finding which explains the inducible characters generally attributed to nitrate reductase (Beevers and Hageman 1980). The variation in this activity is attributed to the plant species, their developmental stage and environmental factors (Pate 1980). Most of the work has been done on leaves because of their ability to actively reduce nitrate and their suitability for experimentation. A few studies have been done on stem nitrate reductase activity (Atkins *et al.* 1979, Andrews *et al.* 1984, Hunter 1985, etc.).

Pizelle and Thiery (1986) reported that the nitrate reductase activity has been found to decrease in order of leaves > branch >inner branch tissue > trunk xylem. Nitrate reductase activity have been found to increase with leaf age but start decreasing when the leaves are fully matured (Muthuchelian *et al.* 1986). As the leaf number increases the nitrate reductase activity has been found to decrease (Abrol *et al.* 1976).

Jones and Whittington (1982) found that the nitrate reductase activity is affected by season and in seedling stage this activity is highest and upper leaves have high nitrate reductase activity than lower ones. At full bloom stage NRA is found to be highest (Harper *et al.* 1972). Plants with a fruit load showed more pronounced diurnal variation in NRA than plants without fruit. Low light intensities and extended dark periods causes diurnal change in nitrate reductase activity (Claussen 1986). Roots and leaves with higher carbohydrate content showed high NR activity and higher rate of nitrate reduction than carbohydrate deficient organs (Carpts Brandner *et al.* 1983, Aslam and Huffaker 1984) in water stressed conditions.

Water stress and high temperature conditions also inhibit nitrate reductase activity, although the magnitude of inactivation varies with the species (Hauffaker *et al.* 1970, Shaner and Boyer 1976, Kauffaman *et al.* 1971, Onweune *et al.* 1971). Pokhriyal

et al. (1990) have found higher nitrate reductase activity in the months of September and February.

Nitrate reductase activity has been found to show positive correlation with the yield characters. Fibres and wood weight per plant and yield potential could possibly be related with nitrate reductase activity at seedling stage (Singh *et al.* 1994).

2.13 Crude Protein

Trees and shrub leaves are useful to grazing animals as a source of protein to supplement the high fibre and moderate to high energy diet provided by grass during the dry parts of the year. Tree leaves have been studied for crude protein by many workers (Kehar and Goswami 1956, Sen *et al.* 1978, Negi 1983, Upadhyay *et al.* 1974, Pal *et al.* 1979)

The seasonal and locational variation in crude protein is fairly wide but percent crude protein content is highest when dry matter was at its lowest (Majumdar 1967). With the advent of monsoon the crude protein values began to drop while in early spring it again rises and at their succulence stage possess practically the same amount of crude protein as the concentrates (Gupta 1983).

Majumdar *et al.* (1967) studied the leaves of 17 species of trees and concluded that during early stages of growth the leaves are rich in crude protein and calcium comparing favourably with the legumes. With the maturity the crude protein and phosphorus content decreased.

Leafiness has been found to be positively correlated with protein content (Paroda 1975). With the advent of rainy season their is rise in crude protein content (Gupta *et al.* 1992). With the increase of tree stuble height the crude protein content also increased (Mendoza *et al.* 1983). The crude protein digestibility from green tree leaves was fairly high compared to the older ones (Jain and Beniwal 1983).

2.14 Carbohydrate

Starch determination in crops is important since the carbohydrate pool is a determining factor in the growth, development and yield. It is stored as a macromolecular reservoir and enriched in the seeds of cereals and bulbs of plants (eg. stems of young plants and specially in leaves) as a temporary storage form of energy (Chaplin and Kennedy 1986).

Lambers and Posthumus (1980) reported that the carbohydrate content of both roots and shoots of *P. lanceolata* was not affected by light intensity. Vandana and Bhatt (1996) reported that the sugar content of leaves and roots in *Sesbania* species decreased as the light intensity decreased. In the stem, sugar content increased with plant age. Starch content in leaves and roots has not been found to show any special trend according to age of the plant while in stem, starch content increased as the light intensity decreased.

As a result of water stress, the sugar content of leaves increased as the starch content decreased (Eaton and Ergle 1952). A direct correlation between starch content and PN was reported in sunflower and soybean (Potter 1980). Naidu and Swami (1996) also reported that monthly data on the leaf starch content and PN both expressed per unit leaf area were positively correlated and accumulation of starch content increased with

the increasing PN.

2.15 Mimosine

Mimosine is a free amino acid which acts as antimetabolite inhibiting the utilization of tyrosine needed for formation and growth of hair and wool. Mimosine gets degraded in to DHP (3-Hydroxy 4(1H)pyridone) in the rumen of the ruminants like cattle and goats through an enzyme present in some of the mimosine containing cells of *Leucaena.*

Krishna Murthy and Mune Gowda (1983) determined mimosine concentrations in *Leucaena* cultivars. They found higher concentrations in growing tips (8.84 to 2.15%), tender pods (5.42 to 1.42%), tender leaves (4.95 to 0.97%), tender buds (3.86 to 0.19%), spread leaves (3.35 to 0.22%), young stems (2.03 to 0.32%) and older leaves (2.68 to 0.15%). Relwani and Khandale (1988) reported that the mimosine content in the newly emerging leaves was higher in cool winter (October) compared to May and July, warmer months of summer. There was significant negative correlation between mimosine content and lignification (Arora and Joshi 1986). While reported higher mimosine level during the summer months from June to August and lower in winter and early spring, probably due to the higher frequency of precipitation in summer and increased dry matter accumulation during winter, mimosine concentration showed a tendency to increase with the age of plants. There was a negative relationship was found between dry matter and mimosine content (Joshi *et al.* 1986).

2.16 Biomass and Production Dynamics

The process of production based on carbon assimilation and absorption of mineral nutrients and their fate in terms of flow of energy and cycling of minerals through primary producers, or green plants and secondary and tertiary producers such as herbivores, carnivores, detrivores, microganisms, decomposers and fixers, etc. have proved to be the most exciting study in ecosystem analysis for management purposes. India has been an active participant of many international efforts i.e. International Biological Programme-IBP-1964-1974, Man and Biosphere Programme-MAB-1972, special committee on problems of the Environment SCOPE 1974 (Continuing), United Nations Environment Programme-1974 (continuing) in revealing the structure and function of the Biosphere.

Ovington (1960) remarked that "there are abundant data of the productivities of different woodlands in terms of the volume of marketable stem but relatively few data of the weights of bole, branch, leaf and root materials produced. The literature available on temperate and western pacific regions is reviewed by Ovington (1962, 1965), Bray and Gorham (1964) and Kira and Shidei (1967). Misra *et al.* (1967) remarked that "Surprisingly little is known about the effect of monsoon on tropical deciduous forests. In 1967 systematic studies on biomass production were started by Misra and his co-workers at Varanasi. Estimates of forest biomass and productivity are now available from the following regions: (1) tropical dry decidaous forests in Vindhyan Plateau region (Misra *et al.* 1967, Desh Bandhu 1970. R.P. Singh 1974, K.P. Singh and Misra 1978); (2) Tropical deciduous forests in Dang region, Madhya Pradesh Pandeya *et al.* 1970, 1972, Vyas *et al.* 1972); (3) Tropical Rain Forests in Western Ghats (Rai 1981); (4) Central and Eastern Himalayan tropical moist and temperate forests (Chaturvedi and Singh 1987 a,b, Rawat and Singh 1988 a,b, Toky and Ramakrishnan 1983, and Rana *et*

al. 1988, Joshi *et al.* 1990, Sah *et al.* 1994). These studies have clearly brought out the relationship between the various components of trees. In the recent studies on the woody biomass production it has been found that the production of main bole (which is the commercial product from forests to be used for timber, fuel or pulp) has a relationship with the other parts (Branches, twigs, leaves, fruits and roots in case of non coppicing species).

In most of these studies the production has been attempted on per tree basis. In cases where the area based production has been worked out (Desh Bandhu 1970) due to lack of age factor the productivity estimates have not been attempted. But on dry deciduous species, it has given precisely the contribution of each species on area basis subject to the change in habitat and specific plant density.

May and Webber (1982) have reported that the patterns of aboveground standing crop, belowground biomass, and above: belowground ratios are controlled by water availability, length of growing season, exposure and soil stability. Sah *et al.* (1994) have reported that the canopy biomass and total biomass replacement was maximum during the rainy season, whereas, the replacement of the root biomass was greater during the winter. Several studies have been done on the partitioning of biomass in different parts of trees by Rana *et al.* (1989) on Central Himalayan Sal, by Singh and Yadava (1991) on oaks in Manipur and by Lodhiyal *et al.* (1992) on *Populus deltoides.* They all reported that maximum biomass partitioning have been found in bole. For *Populus deltoides* Lodhiyal *et al.* (1992) reported that of the total biomass, the allocation to different components was: Bole wood- 49.4-53.9%; bole bark, 6.7-7.8%; branch, 8.5-11.9%; twigs, 2.8-3.5%; leaves 6.0-9.3%; stump + roots, 11.9-13.0%; lateral roots, 6.0 -7.0%; and fine roots, 0.9-1.2%.

Certain studies on mini rotations of species like *Sesbania sesban, S. grandiflora* and *L. leucocephala* have been conducted at high density in 2-3 years rotation under coppice farming (Gupta *et al.* 1983, Rai *et al.* 1983, Pathak *et al.* 1984). Gupta *et al.* (1983) reported maximum biomass of 60 kg/tree at 4.5 years age on canal side plantations of *Sesbania sesban.* In *Sesbania grandiflora,* Rai *et al.* (1983) reported 71.3 t/ha biomass production. Pathak *et al.* (1984) reported 74.32 t/ha mean annual productivity in K8 variety of *Leucaena leucocephala.* All of them have reported a linear relationship between collar diameter, dbh, height and the biomass.

Khan and Pathak (1996) evolved biomass prediction models in *Leucaena leucocephala.* They observed high correlation between biomass components with dbh followed by collar diameter. They presented biomass tables based on dbh classes for each components with equation viz., Total above ground biomass = -1 + 0.0606 $(1+dbh)^{2.6647}$ (R^2 = 0.98). They also observed that variation in biomass increased up to 6.5 years and then declined with maturity. In an earlier study Khan and Pathak (1986) observed that collar diameter measured at the ground level played a significant role in predicting the biomass components. Better prediction of the leaf and pod production was possible through the logarithmic transformation of the data.

Khan *et al.* (1990) while discussing the methodology for biomass prediction in multipurpose trees and shrubs found that as against the linear relationship, cpstatistic was better for optimum prediction of the biomass. Through the system analysis methodologies it was possible to accurately predict the growth and biomass production in *Acacia tortilis* on varying sites with precise accuracy (Khan *et al.* 1994). Similarly growth and production models for *Hardwickia binata* were also produced by Khan *et al.* (1993). In this study, the dbh was found to give the best prediction of biomass and the wood volume.

In trees, the current productivity rises to a maximum during the active growth phase but declines with maturity, so the average rate continues to rise until the current rate falls to equal it. In case of *Pinus sylvestris* (Peterken and Newbould, 1966) found both to be equal at 45 years.

The yields of energy plantation in various regions of the World are summarized by Anderson *et al.* (1983). It indicates that the intensively managed plantations of carefully selected stocks achieve high productivities by efficient use of incoming solar radiation. Plants like *Eucalyptus* and *Leucaena* have given very high productivities in tropics. Specially selected stocks of poplar, willow and sycamore have given an yield of 30 t/ha/yr on less productive areas in drier regions of USA. The productivity thus varies with site quality, tree selections and cultural practices viz., fertilizer and irrigation.

Horn (1971) analysed the monolayer and multilayer growth pattern of trees as related to their successional stages. The light interception below 20% of the light intensity becomes important in forests because of the photosynthetic efficiency of leaves adopting to it. The monolayer species casts more shade compared to the multilayered one and thus the succession starts with multilayered ones and reaches towards monolayer one. These are the biological adjustments in species and are unique in the tropical systems. Ramakrishnan (1978) further remarked that the higher productivity of tropical forests may be owing to their growth pattern and the canopy structure which needs to be studied in detail.

Relative growth rate (RGR) is the most important index of productivity. The possible influences on RGR are many fold and complex in their interactions. Some of these influences are strongly associated with pattern of ontogeny and are relatively immune to manipulation by the foresters or agronomists, though perhaps amenable to the efforts of the breeder.

Productivity or RGR depends mainly on the rate of assimilation and the partitioning of photosynthates among photosynthetic and non-photosynthetic tissues. The partition of leaf area ratio (LAR) permits a fine analysis of growth. Leaf weight ratio (LWR) is a quantity strongly effected by ontogeny (Ledig *et al.* 1970), while specific leaf weight (SLW) is a sensitive measure of environmental influences (eg. Evans 1972). Thus the partition of LAR into LWR and SLA results in partial separation of endogenous and exogenous influences on leafiness and on growth (Ledig 1974).

Net assimilation rate (NAR), an index of physiological activity, is the rate ofdry matter accumulation per unit leaf area. It is a measure of the efficiency of energy capture and conversion of carbon conservation including the losses during respiration. Relative growth rate and net assimilation rate have been reported to have a linear relationship with light intensity (Pandey and Sinha 1977). The shoot: root ratio is often considered to be stable for a species under any given set of environmental conditions (Waring 1970). On this basis, Thornely (1972) developed a model to account for the partition of assimilation between leaf, stem and roots. Leaf, root and stem of loblolly pine seedlings are characterised by seasonal periodicity in growth. Allocation of dry matter to the leaves and other organs, showed a temperature dependence. Daily growth rate based on leaf biomass showed even greater difference in temperature dependence between species.

2.17 Litter Production and Dynamics

Litter is the dead accumalated parts of a tree. Plant litter plays a major role in the trophic structure and functional characteristics of terrestrial ecosystems by acting primarily as an energy source for heterotrophic soil organisms and as a large reservoir for plant mineral nutrients (Chapman 1976, Singh and Gupta 1977). Macfadyen (1963)

Whittaker (1975) and Ola *et al.* (1992) have indicated the importance of litter production to energy flow and nutrient cycling in temperate ecosystems by pointing out that a very large proportion of the energy fixed in primary production reaches the soil as dead organic matter.

Bray and Gorham (1964) reviewed the litter production in the forests of the World. Several studies have been carried out from time to time on different forest types as on temperate forests. Madge (1969), Lee and Wood (1971), Sanchez and Sanchez (1995) on tropical forests. Went and stark (1968), Cooper (1982) on rain forests of South America.

Intensive studies concerning litter fall in forest stands have been conducted in many parts of India notably from deciduous forests of Varanasi (Singh 1968), terrestrial ecosystems (Singh and Gupta 1977); Oak conifer forests in Kumaun Himalaya (Pandey and Singh 1981); pine ecosystem in Meghalaya (Ramakrishnan and Das 1983), *Alnus* plantations in eastern Himalaya (Sharma and Ambasht 1987); *Dalbergia* forest in northern India (Rajvanshi and Gupta 1980), dry evergreen forests (Visalakshi 1993) sacred grove forests of Cherrapunji (Khiewtam and Ramakrishnan 1993); Garhwal Himalaya forests (Pant and Tiwari 1992). Information on litter production in the semi-arid Bundelkhand forests is lacking.

In a *Dalbergia sissoo* forest ecosystem, Rajvanshi and Gupta (1985) reported annual litterfall of 4790 kg dry matter/ha/yr of which leaves formed 69% of the total. Gupta *et al.* (1988) found that in *Populus deltoides - Leucaena leucocephala* agroforestry system, annual litterfall amounted to 5700 kg/ha/yr.

Leaf fall is found to be variable through out the year and the highest value were observed during the dry seasaon (Sanchez and Sanchez 1995). Twig litter fall was found to be highest on the start of winters, while floral parts + seeds / fruits were maximum during the onset of summers (Pant and Tiwari 1992).

Rate of litterfall is controlled by environmental factors (Kunkel-Westphal and Kunkel 1979). Spain (1984) reported that litter fall was positively correlated with temperature. Sanchez and Guevara (1993) showed that there is a relation between litterfall and rainfall. Spain (1984) found that litterfall is inversely correlated with altitude and latitude. Likewise, soil fertility and the slope can also affect the litterfall (Jordan 1983). In arid and semi-arid regions soil moisture plays important role in maintaining the litter fall of trees.

2.18 Light Use Efficiency

Light is one of the most important factor affecting growth, development and competition of the plants as it is directly concerned with photosynthesis and the production of growth and biomass.

The plant species vary greatly with respect to their light absorption and variability in solar energy utilization among different cultivars is well described by various workers (Kanda 1975 and Bhatt and Misra 1990). The potentiality of plants to trap solar energy and convert it into chemical energy determines their dry matter yielding capacity. Leaf morphological characters such as leaf surface features and leaf orientation play an important role in light absorption and consequently the dry matter

yield (Loomis *et al.* 1971). Augmentation in dry matter production through genetic manipulation for high photosynthesis has received much attention where the energy efficiency and compartmentation of energy are well defined (Nasyrov 1981). The absorptance property of leaves is determined by the external environment. Leaf absorptance is increased as one goes from southern latitudes to the northern latitudes (Dadykin and Bendenko 1960).

The process of photosynthesis depends upon the absorption of light. When light falls perpendicular on a leaf, reflection is minimum than transmission. As a result of this, absorption is held relatively constant in a wide range of incident angle (Tagayava and Brandt 1960). The reflectance of the leaves, in general, increases with the angle of incidence. It has been found that light of different colours show different absorptance and reflectance. Mc Cree (1972) reported that the efficiency of blue light is nearly twice than that of red light in a low flux density.

By a comparison of the total accumulated radiation during the growing season with corresponding biomass production, photosynthetic efficiency can be worked out (Wassink 1959, Singh and Misra 1968). Dwivedi (1971) reported that the maximum average daily energy trapping capacity of *Dichanthium annulatum* i.e. 34.17 k cal/m^2/day was obtained during the month of July, whereas, the maximum energy conserving rate, i.e. 23.20 k cal/m^2/day was found during the month of December.

Dhyani (1989) reported that in *Populus euramericana* out of the total 448.75 wm $^{-2}$ energy absorbed, 366.05 (about 81.6%) of energy was lost by reradiation and of the remaining, 0.9% by transpiration and 17.5 % by convection. He further stated that there was pronounced effect of altitude on energy exchange rate. At 550 m altitude after reradiation maximum amount of energy was lost through transpiration while at 3600 m altitude after reradiation maximum energy was lost through convection. It has always been found that the reradiation is the dominant factor for the dissipation of the absorbed energy than the transpiration and convection (Gates and Benedict 1963).

Sims and Singh (1971), calculated the efficiency of solar energy fixation for total productivity values of each parts. This is based upon conversion of plant dry weight to calorific value by factors of 4 k cal g^{-1} (16.7 k Jg^{-1}) for the above ground material and 4.7 k cal g^{-1} (19.7 k Jg^{-1}) for the below ground materials.

2.19 Energy Dynamics

The study of energy transformation within an ecosystem is called ecological energetics (Phillipson 1966). There is an increasing tendency of using energy estimation in analysing the level of production in various ecosystems rather than only the phytomass because it gives a finer picture of the systems productivity. It is well known that the energy that drives the ecosystem on the planet earth comes from the sun. At the outer limits of our atmosphere 118872 g cal/cm^2/ yr of solar energy are received of which 34 per cent is reflected back and 10 per cent is held by Ozone layer, atmosphere and cloud and 56 per cent reaches the earth's surface (Lindeman 1942). But there is wide local variation in solar radiation input to the earth's surface depending upon the cloud cover, clarity of the atmosphere and other factors.

During photosynthesis, solar energy is captured by green plants and they convert the same into chemical energy which passes from organism to organism as food and ultimately gets converted into mechanical and heat form in cellular metabolism. The production potential of an ecosystem, therefore depends much on the efficiency with which the vegetation accumulates this energy in the net primary production. Ovington (1963) emphasized the significance of assessing the rate of energy fixation, its accumulation and release to provide a basis for integrating the diverse processes concerned with the energy flow in various communities. Estimation of energy flow along with possible quanitity of dry matter transfer may be obtained by using calorific values. The energy flow helps in preparation of energy budget and calculating energy conserving efficiency of the ecosystem which gives an overall impression of the ecosystem energetics.

A knowledge of the energy relationship is essential for- a)the estimation of energy flow, b)evaluation of the amount and possible quantity of energy transfer, c) preparation of energy budget and the calculation of energy conserving efficiency of the ecosystem. Having this aim in view, an attempt was made by various workers to determine the calorific values of different components of the plant on ash free dry weight and energy retention, release and fixation by terrestrial communities.

In terrestrial plant communities studies regarding caloric value, energy content, flow of energy and ecological energy conserving efficiency have been made by various investigators (Teal 1957, Golley 1965, 1969, Gates 1962, Odum 1962, Lieth 1965, 1962, Choudhary 1967, 1974, Singh and Misra 1968, Dwivedi 1971, Gupta 1972, Singh 1972, Singh and Yadava 1973, Billore 1973, Misra 1973, Ambasht and Singh 1975, Pandey 1977, Pandey and Sant 1979, Kumar and Joshi 1980, Lamotte and Bourliere 1983, and Lakshmanachary 1987). Rana *et al.* (1989) reported that the calorific value of tree wood ranged from 4698 cal g^{-1} in *Quercus leucotrichophora* to 4712 cal g^{-1} in *Pinus roxburghii.* For leaf, it ranged from 4015 cal g^{-1} in *Q. lanuginosa* to 4312 cal g^{-1} in *P. roxburghii.* The net annual energy fixation varied from 56.6 x10 6 k cal ha^{-1} yr^{-1} (Chir Pine-mixed broad leaf forest) to 126.5x10 6 k cal ha^{-1} yr^{-1} (*tilonj* dominated mixed oak forest). Net annual energy fixation in Sal old growth forests exhibited almost equal accumulation of energy in bole and leaf component (21x10 6 k cal ha^{-1} yr^{-1}) while in *tilonj* dominated mixed oak forest bole have stored highest energy (34x10 6 k cal ha^{-1} yr^{-1}) and leaf have found to exhibit 21x 10 6 k cal ha^{-1} yr^{-1}. Energy storage in woody components showed a range of 731.6 - 2965.9 x 10^6 k cal ha^{-1} and in foliage and herbaceous aboveground parts, 29.2 - 132.9 x 10^6 k cal ha^{-1}. The net annual energy fixation amounted to 21.1 - 77.2 x 10^6 k cal ha^{-1} yr^{-1}, in woody components and between 21.0 and 27.7 x 10^6 k cal ha^{-1} yr^{-1} in leaves and herbaceous above ground components. Golley (1961) reported in three old field communities at Michigan and Georgia that energy on seasonal basis increases from rainy to cool and hot weather and found highest in fall and winter with minimum during spring followed by summers. Chaudhary (1974) reported that energy content of green grass biomass of *D. annulatum* gradually increased from January and reached its peak in December. Singh (1988)

observed peak standing crop of above ground energy value during November in *Bothriochloa pertusa* grassland while in the standing live component it was during October.

Chapter 3

Experimental Site

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MATERIALS AND METHODS

3

Experimental Site and Materials and Methods

The proposed investigations were carried out on morphological, ecological and physiological behaviour on *Leucaena* variants (S24, S22, S14, S10 and K8) to understand their behaviour contributing to the biomass production and energetics. These variants were from the final evaluation trial where K-8 was used as control.

3.1 The Experimental Site

i) Geographical situation: Jhansi lies in part of Uttar Pradesh state and forms a significant district in the Bundelkhand region. Jhansi is situated at 75.35 east longitude and 25.27 north latitude at about 275 m above the mean sea level. Due to its position in the south-West corner of the state it bulges in the Madhya Pradesh which surrounds it from three sides (Fig. 3.1)

ii) Geology: The Vindhyan high lands are formed by sedimentary of cuddapah and Vindhyan systems i.e., sand stone, lime stone, shales, conglomerate, quartzite, gneiss and igneous rocks like granite, dolomite and diorite. The upper Vindhyans have massive sand stone with small conglomerate at the base and rest directly on the genesis. The lower Vindhyans intervene between *Bijawar* and upper Vindhyans and consists of sandstone and shale in small out crops. The Bijawar series which succeeds the genesis occupy a narrow strip on south and consist of sandstone limestone and slates.

iii) Surface relief: The whole region of Bundelkhand is covered with Vindhyan ranges presenting undulating plains with rocky hills at places or ravines of the river beds running east to west. The extreme southern part is Vindhyan plateau rising in two escarpments, one of which rises to a height of about 90 to 160 m above the plains and is not well defined. The second one rises to an average height of about 300 m and is

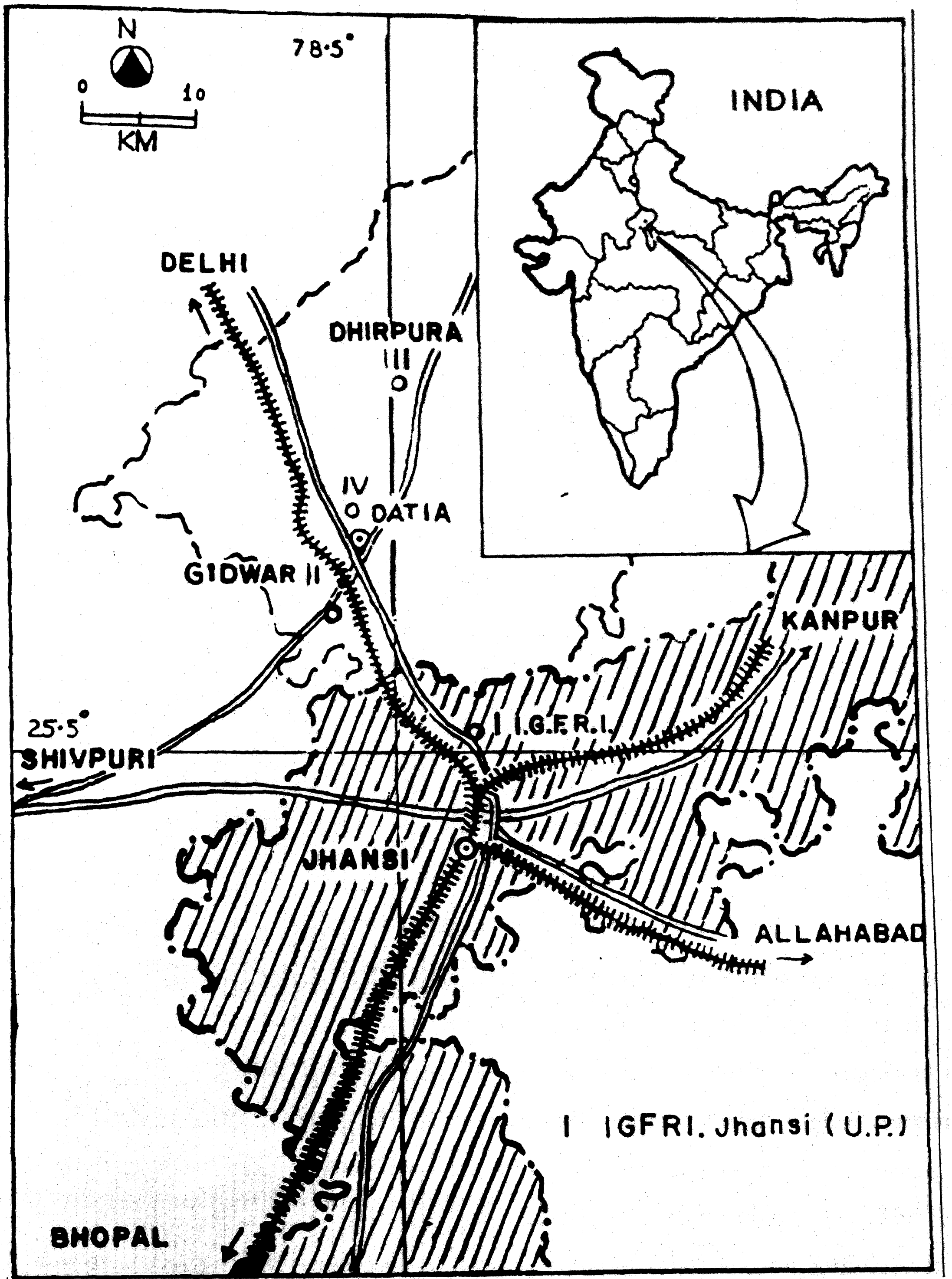


Fig. 3.1: Location of the study site

more clearly defined. The principal rivers that drain the southern tract are Shahjad, Sajnam and Jamini flowing towards north. The north part is drained by Betwa, Pahuj and Yamuna having deep and long stretched ravines. The slope is from south towards north with sharp gradient in the south and gentle in the north (Singh 1971).

iv) Climate : The central situation of Bundelkhand region shows the feature of transitional climate between maritime climate of east coast and tropical continental dry climate of west. The mean rainfall based on 65 years average is 950.4 mm with almost all the months with some rain. The ombrothermic diagram based on 65 year data of rainfall and mean temperature drawn on a scale of P=2T shows four months as wet and the remaining months dry (Fig. 3.2 A). The months of June to September being wet show the peak rainfall exceeding 300 mm during July followed by August with more than 250 mm. September also had rainfall of about 170 mm. This feature of long term average with peak mean temperature of May and minimum of January shows that the area is sub - humid. In one of the studies Hazra (1981) found the area as semi - arid with moisture index from -40 to -60.

During the study period (1995 - 1996) the climatic features show a very erratic situation whereby during both the years four months were totally dry without any rainfall (Fig. 3.2 B and C). During 1995 the total rainfall was 829.9 mm with 42 rainy days while during 1996 it was 952.7 mm on 52 days. Thus there was a net increase of 122.8 mm on the 10 days. The month of July received maximum precipitation during both the years with maximum during 1995. the rain during July was more spread over in 1996 compared to 1995 (18 compared to 15 days). As the trend is , August in the second rainiest month. During 1996 there was 316.6 mm rain during August compared to 211 mm in 1995. The situation was just like July showing higher intensity with higher rainfall in 1996 compared to 1995 with low rainfall and longer spread over. The most interesting feature is 110.57 mm rain on two days during October 1996 compared to no rain during 1995. The following two months were rainless up to December. Rain during

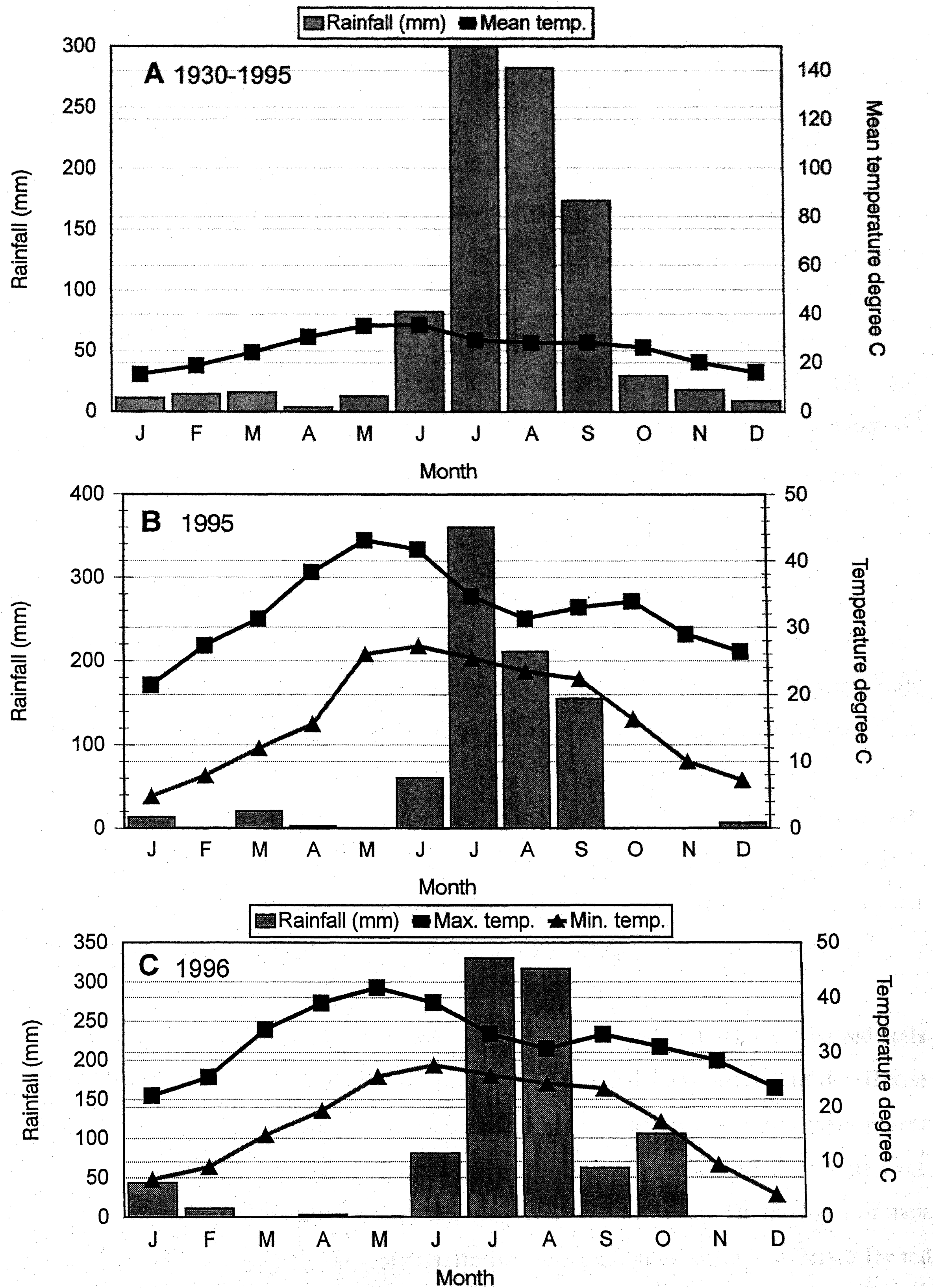


Fig. 3.2: Ombrothermic diagram and climatic parameters during the study period at Jhansi

September was quite low during 1996 compared to 1995. The year 1996 showed five months from June to October with more than 50 mm rain while in 1995 only four months from June to September were rainy.

Jhansi receives very high summer temperature with peak mean maximum during May (43.1 ^{0}C during 1995 and 41.8 ^{0}C during 1996). The mean minimum temperature was lowest during January (4.8 ^{0}C in 1995 compared to 6.8 ^{0}C in 1996). The figures show very low variation between maximum and the minimum temperature during July and August during both the years while it was maximum during March - May and November - December. The narrow range of variation during July and August is conducive to fast growth and leaf expansion while the broader range is responsible for reproductive growth and seed setting.

The evaporation demands are maximum in May (13.9 mm/day) and the minimum in January (2.1 mm/day). The evaporation demands in October, November, February, April and May are more than the precipitation (Fig. 3.3). The months with high evaporation demands are also associated with longer duration of bright sunshine hours (8-10.6 hours) and higher wind velocity (4-9.6 km/hour). These factors affect relative humidity and all these factors contribute to the soil moisture, temperature, plant growth and anthesis. A noteworthy feature of Jhansi is also daily peak temperatures during summer months when for a few days to a week the peak temperature may touch beyond 48 ^{0}C (during the last week of May or first week of June).

v) Soil : In this tract there are two major soil groups viz, red and black . The red soils are normally coarse, grained upland soil and the black soils are heavy and distributed in low lying areas. These soils are residual in nature and are formed from parent material in situ. The red soils originated from gneiss and granite and some time even from sand stone, while the black soils are formed from lime stone. On the basis of their colour and texture the two soil types are further grouped in to Rakar and Parwa for red

soils and Kabar and Mar for black soil. The experiments were carried out on red soils.

v.i) Soil characteristics of the site: The soil characteristics were studied as per the method of Piper (1957) and Jackson (1962). The results are presented in table 3.1.

Table 3.1 : Edaphic parameters of the plantation site (pH 6.6 - 6.9, water holding capacity 27 - 29 %, conductivity 31.3 - 51 m mho/cm^3).

Month	Depth (cm)	Organic carbon	Available nitrogen (kg/ha)	Available phosphorus (kg/ha)	Available potassium (kg/ha)	Calcium (%)	Magnesium (%)
Sept. 95	0 - 15	0.28	265	32.1	224	0.017	0.011
	15 - 30	0.22	207	26.6	196	0.017	0.012
March 96	0 - 15	0.37	274	32.1	210	0.014	0.014
	15 - 30	0.26	207	27.8	196	0.017	0.015

a) Soil colour: The soil of the experimental site was reddish

b) *Soil pH:* The soil pH was taken from the experimental site at 15 cm and 30 cm depths. At 15 cm depth it was 6.7 while at 30 cm depth it was 6.6 indicating its neutral nature.

c) Soil conductivity: The conductivity varied from 51.0 to 31.5 m moles /cm^3 at 15 and 30 cm.

d) Water holding capacity: The water holding capacity was in the range of 27-30% with low values at 30 cm depth.

e) Soil moisture: Soil moisture percentage at 15 cm depth was found to be maximum in the month of August while minimum in the month of May. At 30 cm depth maximum soil moisture percentage was found in the month of August and minimum

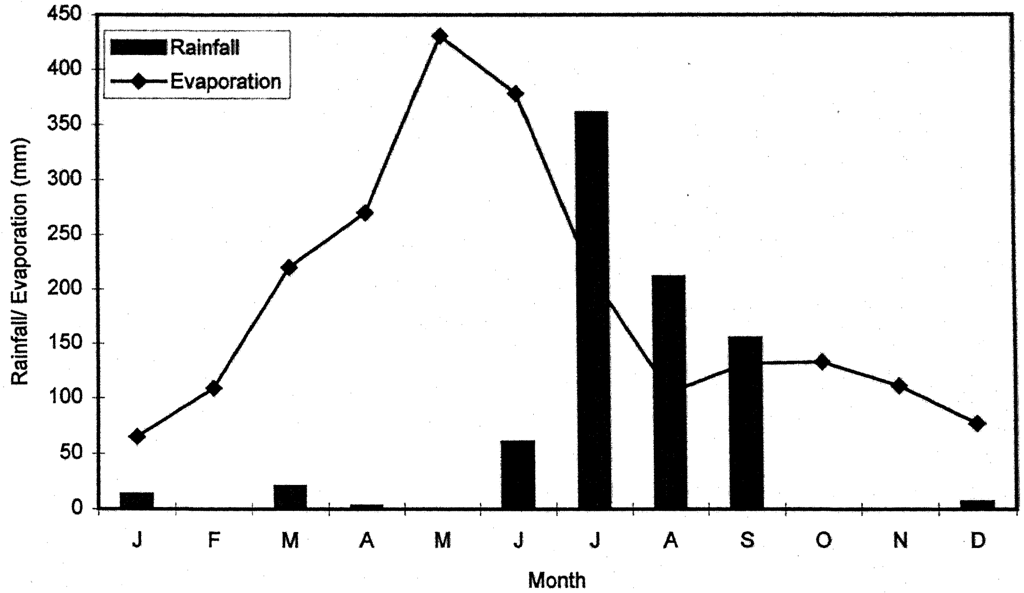


Fig. 3.3: Rainfall and evaporation pattern at experimental site, Jhansi (1995-96)

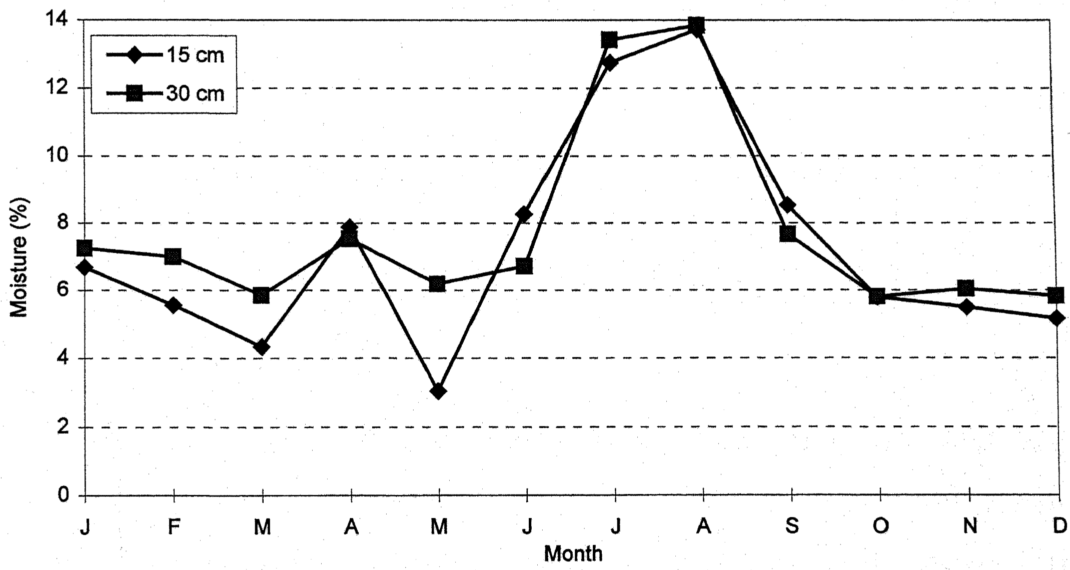


Fig. 3.4: Soil moisture at two levels in the *Leucaena leucocephala* plantation (1995-96)

in the months of March and October (Fig. 3.4) .

f) Soil organic carbon: The soil organic carbon content was found to be maximum in the month of March at both depths. This behaviour indicates utilization and build up of carbon in the soil during cold dry months when the growth activities are dormant.

g) Soil nitrogen: Available nitrogen content was high in the month of March at 15 cm depth while at 30 cm depth it was found to be same during both the observation months (Table 3.1).

h) Soil phosphorus: Soil phosphorus content was found to be same in both the months while at 30 cm depth it was high in March.

i) Soil potassium: Soil potassium content was found to be high in September at 15 cm depth while at 30 cm depth it was found to be same in both months.

j) Soil calcium: Calcium was found to be almost same at both the depths in both the months although at 15 cm depth it was less during March.

k) Soil magnesium: The magnesium percentage was found to be high in the month of March at both the depths compared to September.

3.2 Experimental Materials

The growth and biomass production of selected varieties of *Leucaena leucocephala* has been studied at the Military padao area of the IGFRI experimental farm. It was a sloppy calcareous degraded grassland area where calcium carbonate nodules were quite apparent even on the surface and it was very dry during most parts of the year. The plantations raised during 1989 and coppiced in 1994 were used for the

A

B

Plate 2 : A general view of *Leucaena leucocephala* plantation.
A) A view of different rows.
B) A view of different blocks.

study of growth, phenology, biomass production, litter production and seed production studies. Three plants of each variety were marked for measuring the growth of height, collar diameter and diameter at breast height (dbh). Number of branches, canopy structure and clean bole height were also recorded. Three plants of each variety were uprooted for recording the biomass production data at one and two year growth. The components were separated in to bole, branch, leaf and pod fractions, weighed and finally dried in the hot air oven at 80 ^{0}C.

For early growth, morphological and physiological characters of these varieties the pot culture experiments were conducted at nursery / net house of the Division of Plant Physiology & Biochemistry of IGFRI, Jhansi.

3.3 Research Methodology

3.3.1 Litter Collection : Seasonal pattern of leaf fall, twig fall and shedding of other plant parts was studied by collecting the material under the tree every 15 days. Litter traps (1 X 1 m) were placed under the tree in each replication and the variety. The samples were collected, separated manually in to leaf, twig, pod flower and other miscellaneous parts, weighed and kept in the oven for recording the dry matter at 80 ^{0}C.

3.3.2 Seed Collection : Healthy and viable seeds of *Leucaena leucocephala* variants in uniform shape and size were collected from the plantations. Seeds from individual trees were collected and stored separately.

3.3.3 Raising of Seedlings : The seeds of uniform size of *Leucaena* were scarified and sown in polythene bags containing garden soil and sand (1:1) in the nursery/pot culture house of Plant Physiology and Biochemistry Division during last week of May. The uniform seedlings of 3-4 leaf stage were transplanted in the poreceline pots (29.5 x 20.5 cm) filled with garden soil, farm yard manure and sand (2:1:1 ratio) Each pot contained

only one plant. The plants were reared regularly as per the standard agricultural practices.

3.3.4 Growth Behaviour and Morphological Studies : To study the growth behaviour, biomass production, physiological and biochemical processes in relation to seasonal growth and age during one year of growth, the uniform seedlings were selected. The pots were arranged randomly in rows and distance between two adjacent rows was maintained at 90 cm to allow better light penetration and also to facilitate inter-cultural operations.

3.3.5 Recording of Morphological Data : For recording the morphological and growth parameters three plants of each variety were uprooted at monthly intervals and the observations on plant height, stem diameter, number of branches, number of leaves, root length, number of nodules, leaf area, fresh and dry weight were recorded. For taking fresh weight the plants were washed properly in running water and blotted to remove extra surface water before weighing. The leaf area of fresh leaf was measured by automatic portable leaf area meter (model LI - 3000, USA) before weighing. The samples of each plant parts were dried in electric oven at 80 ^{0}C for 48 hours and then the dry weight was recorded.

3.3.6 Analysis of Growth Data : The different parameters of growth were calculated by using the formulae of Evans (1972) as follows:

i. *Relative Growth Rate (RGR)* :

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \quad g/g/day$$

(Where W_2 and W_1 are dry weights in g at harvest times t_2 and t_1 respectively).

ii. *Root : Shoot Ratio :*

$$\text{Root: Shoot ratio} = \frac{\text{Mean root dry weight}}{\text{Mean shoot dry weight}}$$

iii. *Partitioning of Dry Matter :*

The partitioning of dry matter in different plant parts was calculated as:

$$\text{\% Dry weight} = \frac{\text{Dry weight of individual part X 100}}{\text{Total dry weight}}$$

iv. *Specific Leaf Area (SLA) :*

The specific leaf area is calculated as

$$\text{SLA} = \frac{\text{Leaf area}}{\text{Leaf weight}} \quad (\text{cm}^2/\text{g})$$

v. *Specific Leaf Weight (SLW) :*

The specific leaf weight is calculated as :

$$\text{SLW} = \frac{\text{Leaf dry weight}}{\text{Leaf Area}} \quad (\text{mg / cm}^2)$$

vi. *Leaf Area Ratio (LAR) :*

The leaf area ratio is calculated as :

$$\text{LAR} = \frac{\text{Total leaf area of plant}}{\text{Total plant dry weight}} \quad (\text{cm}^2/\text{g})$$

vii. *Leaf Weight Ratio(LWR) :*

The leaf weight ratio is calculated as :

$$LWR = \frac{\text{Dry weight of leaf}}{\text{Total plant dry weight}}$$

3.3.7 *Growth and Biomass Data from the Plantations* : The coppice growth data of plant height and diameter (Collar diameter and diameter at breast height (1.37 m)) were recorded quarterly from the three replications of the *Leucaena leucocephala* varieties in the field. At the end of one year and two years, selected trees were felled from each replication for recording the biomass data (Newbould 1967). Trees were cut in to one meter segments. From each segment the biomass was separated in to bole, branch, leaf, flower and fruit segments and weighed. From the one meter bole segments, further 5 cm disc was cut by saw, the bark and wood was separated, weighed and kept in the oven at 80 ^{0}C temperature for the determination of the dry weight. Small samples from other parts viz., branch, leaf, pod were kept for the dry matter determination. The below ground parts were also excavated up to a depth of 1 m. Roots were carefully collected, washed and weighed. Sample was also drawn for the determination of the dry matter. The third year biomass was worked out from the basic growth data through the available production models (Pathak *et al.* 1987).

3.38 Physiological Observations : Measurements of photosynthetically active radiation (PAR), air temperature (AT), relative humidity (RH), net photosynthesis (PN), stomatal conductance (CS), intercellular CO_2 concentration (CINT) and transpiration rate (TR) were made in the leaves by using the LI-6250 portable photosynthesis system (LICOR, USA). In each replication fully expanded healthy second and third leaves were used to record the observations. All the measurements were made at ambient CO_2 between 1100 and 1200 hours on a clear sky day. The ratio of PN/TR, PN/CINT were also calculated.

3.3.9 Biochemical Estimations

i. Photosynthetic pigments : Photosynthetic pigments in fresh leaves were estimated by the method of Duxbury & Yantsch (1956) and Comer (1962). One gram leaves were homogenized in 80% acetone and the supernatant was filtered through funnel using filter paper in 50 ml volumetric flask and made volume with acetone. A suitable amount of aliquot was taken in 25 ml volumetric flask and made up to 25 ml with acetone. Concentration was measured by measuring the absorbance of the solution using UVS-119 spectrophotometer at 660 & 640 mu wave length for total chlorophyll, chlorophyll 'a' and chlorophyll 'b' whereas carotene content was measured at 510 & 480 mu. The fractions of chlorophyll were calculated from the absorption values using equation given in A.O.A.C. (1970) and expressed in mg/g of the fresh weight.

Chlorophyll 'a'= 9.93xO.D. (660 mu) - 0.777xO.D.(640 mu)

Chlorophyll 'b' = 17.3xO.D.(640 mu)-2.8xO.D.(660 mu)

Total chlorophyll = Chl a + Chl b

Carotene = 7.0 (O.D. at 480 mu) -1.47 (O.D. at 510 mu)

ii. Nitrate reductase activity : Nitrate reductase activity in fresh leaves was estimated by using methods of Bar-Akiva and Sturbaum (1965) and modified by Kleeper *et al.* (1971). Weighed 0.3 g of fresh leaves and cut into small pieces and placed in 5 ml tubes added 3 ml of 0.2 M KNO3 and 3 ml of 0.1 m phosphate buffer (7.5 pH) and incubated for 2 hours at 30^0-33 ^{0}C. After that, tubes were removed and immersed in boiling water bath for 4 minutes to stop the reaction for effective removal of nitrate accumulation in plant tissues. Cooled the tubes and added 1 ml of 1% sulphonilamide + 1 ml of 0.01% N (1-Nepthalenadiamine hydrochloride) and mixed thoroughly and kept

for 25 minutes for colour development. Subsequently 0.2 ml was taken in separate tube and made the volume up to 6 ml with distilled water. Optical density was measured at 540 mu on UV - VIS-119 spectrophotometer and the nitrate reductase activity was calculated from the optical density and expressed in m u mole NO_2/ g fresh weight /h of the fresh weight.

$$\frac{10 \text{ X O.D. X Total Volume}}{0.09 \text{ X Volume of aliquot taken}}$$

iii. Crude Protein : Crude protein of the samples was determined by multiplying the value of total nitrogen by 6.25. Total nitrogen was determined by micro-Kjeldahl's method (A.O.A.C. 1960). 100 mg oven dried samples were taken in a dry micro-Kjeldahl flask containing 5 ml. $H_2 SO_4$ (Nitrogen free) and catalytic mixture and kept for digestion. The desired material was transferred into volumetric flask and the volume was made up to 50 ml. A suitable aliquot (about 5 ml) was taken in to the distillation apparatus along with 5 - 10 ml 40% NaOH. Ammonia collected in 21% boric acid containing 2 - 3 drops of mixed indicator for 7-10 minutes was titrated with N /5O standard sulphuric acid solution.

$$\text{\% of N=} \frac{\text{Sample titrated - Blank taken X normality of H2SO4 X 100}}{\text{Sample weighed in mg X 100}}$$

Crude Protein = 6.25 X % of Nitrogen

iv. Determination of Sugar and Starch : Sugar and starch content of samples was estimated by anthrone method (Morris 1948). 100 mg ground dried sample was taken into a 15 ml centrifuge tube and 10 ml of 80% ethanol was added to it. These tubes were kept on water bath at 80-85^{o}C for 30 minutes. It was centrifuged and decanted into a 25 ml beaker. Ethanol was evaporated on a water bath at 80 - 85 ^{o}C until most of the alcohol was removed.. This was made up to 25 ml with distilled water. 5 ml of this sugar extract was taken in a 100 ml volumetric flask and the volume was made up with distilled water. 5 ml of this solution was taken in a test tube in ice bath. To

each tube 10 ml of 0.2% anthrone reagent was added. These tubes were kept into a boiling water bath for exactly 7.5 minutes cooled in ice and absorbance was measured at 630 mu on Spectronic-70.

The residue left in the centrifuge tube was dried at 80 ^{o}C in an oven for starch extraction. After adding 2 ml of distilled water, tubes were kept on boiling water bath for 15 minutes. After cooling it 2 ml of 9.2 N perchloric acid was added to it and then made up to about 10 ml and centrifuged. After collecting the supernatant, 2 ml of 4.6 N perchloric acid was added to the residue and made up to 10 ml with distilled water. It was centrifuged and the supernatant mixed with the previous one. This was made up to 50 ml with distilled water. 5 ml of it was taken in a 50 ml volumetric flask and the volume was made up with distilled water. Now 5 ml of it was taken in a tube, kept in a ice bath and 0.2% anthrone was added to it. After keeping it for 7.5 minutes on boiling water bath and cooling in ice absorbance was taken at 630 mu on Spectronic-70. The values for sugar and starch content were obtained by putting the values of O.D. in the standard curve.

v. Mimosine : Mimosine content in leaves of *L. leucocephala* varieties was determined by calorimetric method described by Brewbaker and Kaye (1981). One gram fresh leaf sample was macerated with 9 ml 0.1 N HCl in pastle and mortar and centrifuged for 5 minutes at 2000 R.P.M. 1 ml of supernatant liquid was mixed with 2 ml of 0.1NHCl with charcoal, boiled for 15 minutes on water bath and filtered through Whitman paper No. 42. Two ml of aliquot was taken mixed with 5 ml of EDTA solution (Na_2 EDTA $2H_20$ 1g in 4 liter distilled water) and 1 ml solution of ferric chloride (2 g Fe Cl_3 $6H_20$ dissolved in 500 ml of 0.1N HCl) and mixed well. The absorbance was measured at 535 mu on Spectronic-20 along with the control sample. The values for mimosine content were obtained from the standard curve.

vi. Determination of energy value in plant samples : The energy in terms of calorie

value was estimated in the dry material of leaf, stem and root. The dried material was powdered in a sample grinder (20 mesh screen) and 1 g pellets were prepared from the fine powder. These pellets were dried and kept in a desiccator for the determination of calorie values using an oxygen Bomb Calorimeter (model -RSB 3). The calorie value was presented in kcal/g dry wt.

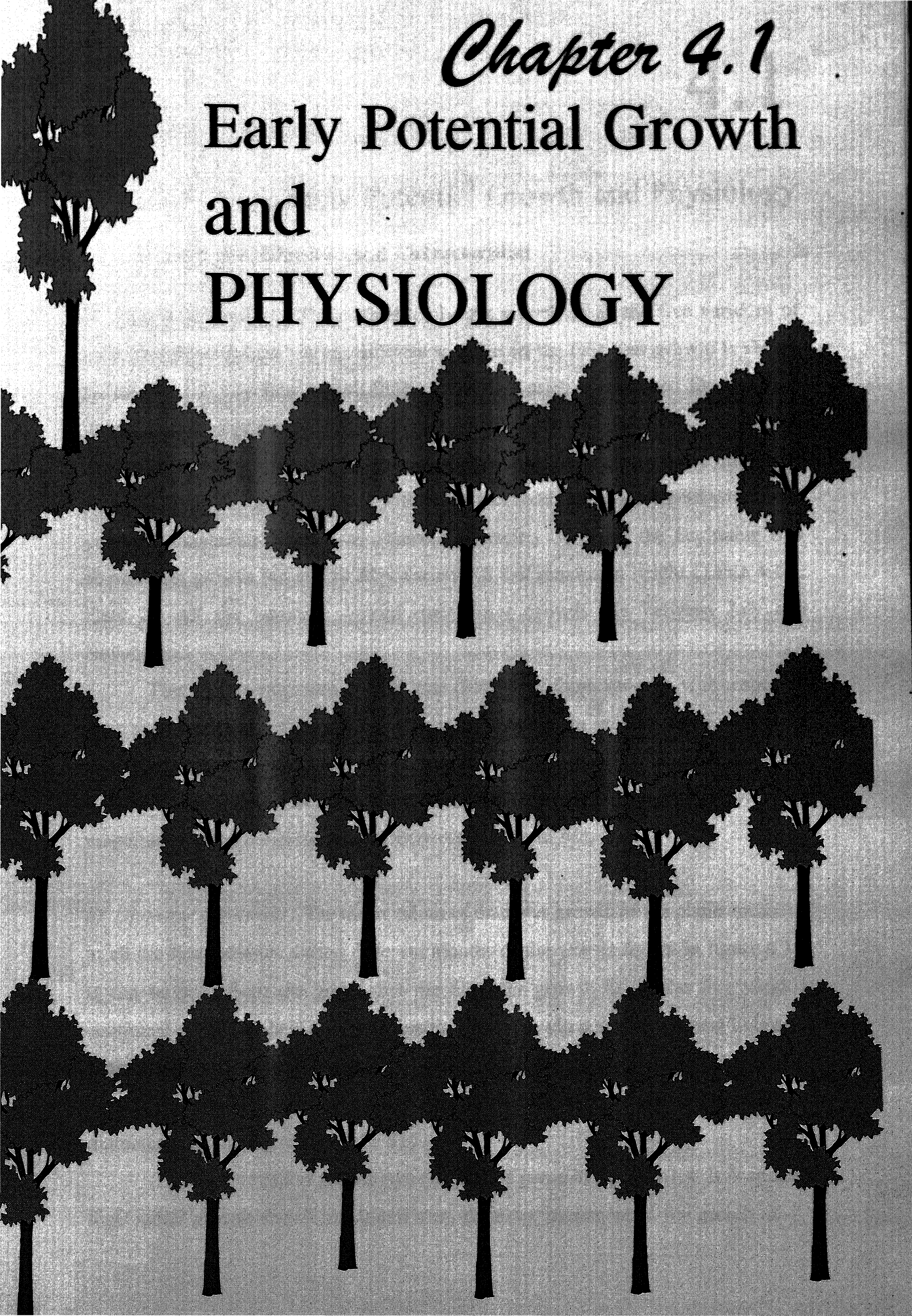
vii. *Energy flow and ecological efficiency* : The dry matter values of the plant biomass were multiplied by their energy value to obtain the energy allocation pattern to different components of the biomass. From these data the energy flow diagrams were prepared for the year. The ecological efficiency was calculated by dividing the total energy produced by the utilizable solar energy received per unit area multiplied by 100.

viii. *Statistical analysis and presentation of data* : The data were analyzed statistically and significant responses at 5% level have been compiled using the methods of Fisher and Yates (1963) and Panse and Sukhatme (1967). The critical difference (CD) has also been worked out for comparing the mean values of the treatments and their effects on the stages and their interactions.

Correlation coefficients among various important morphological, physiological and their interdependence of the characters. Graphical representations have been made to facilitate easy understanding of the table and responses to the treatments.

Chapter 4.1

Early Potential Growth and PHYSIOLOGY



4.1

Early Potential Growth and Physiology

4.1.1 Growth and Morphological Characteristics

a) Height Increment : The cumulative height growth of all the five varieties of Leucaena leucocephala during different months in the first year growth is shown in figure 4.1.1. The first growth flush in all the varieties continued for 150 days from the date of germination. The second growth flush was observed from March (after 270 days from the date of germination). Although no remarkable difference was observed among the varieties with respect to their height increment within one year, the maximum height was observed in variety S10. In the beginning S24 showed fast growth but at 150 days variety K8 had maximum height (Table 4.1.1, Plate 3). All the varieties showed their faster growth rate between July and November.

The relative extension growth rate (REGR) of these varieties with respect to their age is shown in figure 4.1.2. The rate of extension growth was found to be highest in almost all the varieties at the seedling stage i.e., July to November. Again there was an increase in relative extension growth in all the varieties with low magnitude during different months between March to May.

b) Diameter Increment : The mean values of diameter growth of the plants measured in all the five varieties during different months of the year is shown in figure 4.1.3. It can be seen from the graph that the diameter growth in all the five varieties continued up to 270 days after germination. The growth decreased during February-March and again increased in April-May. After one year K8 and S22 attained maximum diameter followed by S24 and S10 which were at par, while minimum diameter growth was recorded in S14.

The relative radial growth rate (RRGR) is given in figure 4.1.4. It is apparent that radial growth shows maximum stem diameter increment in the month of

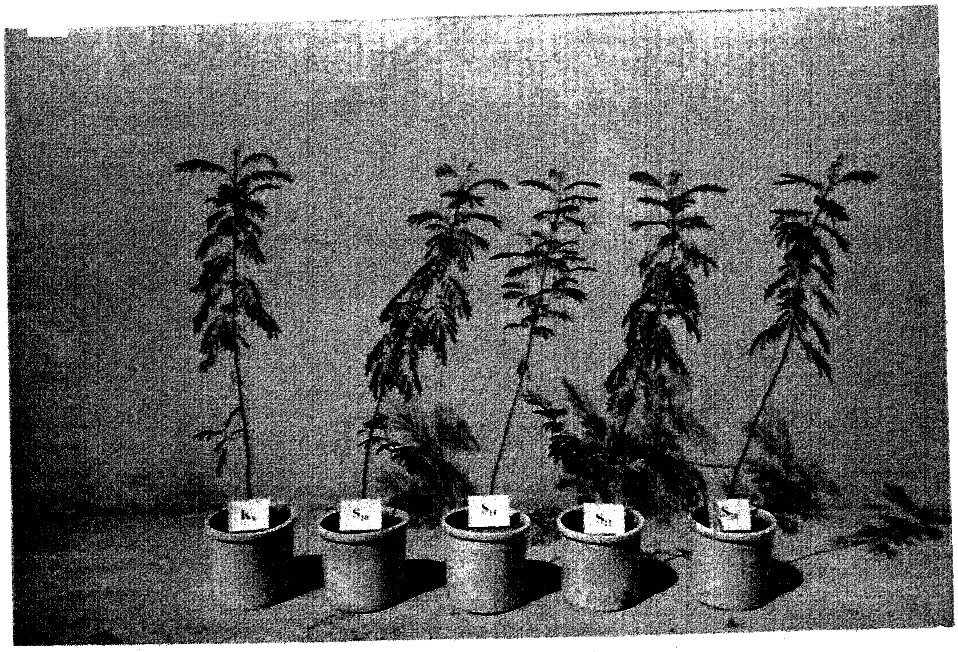


Plate 3 : *Leucaena leucocephala* seedlings in pot culture (6 months growth).

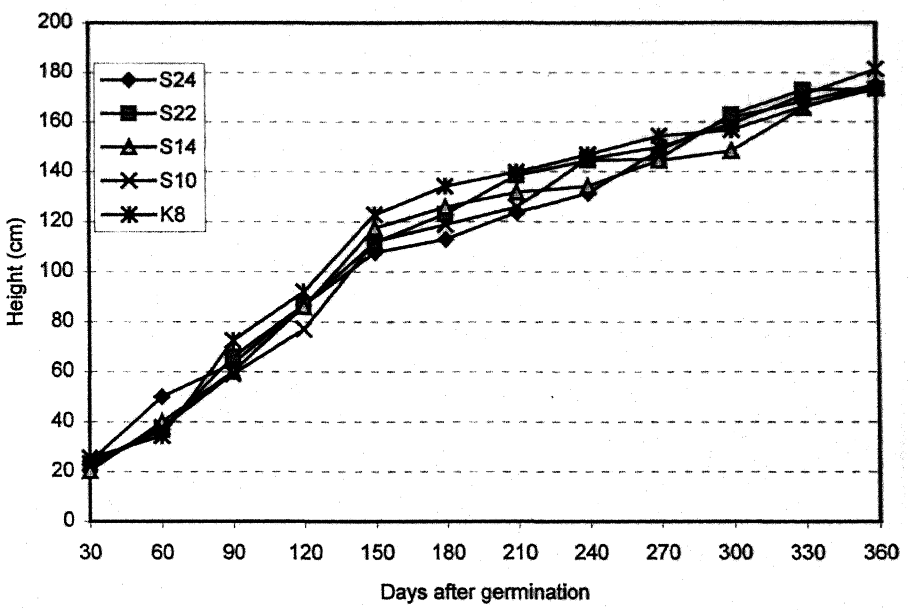


Fig. 4.1.1: Height growth in *L. leucocephala* varieties

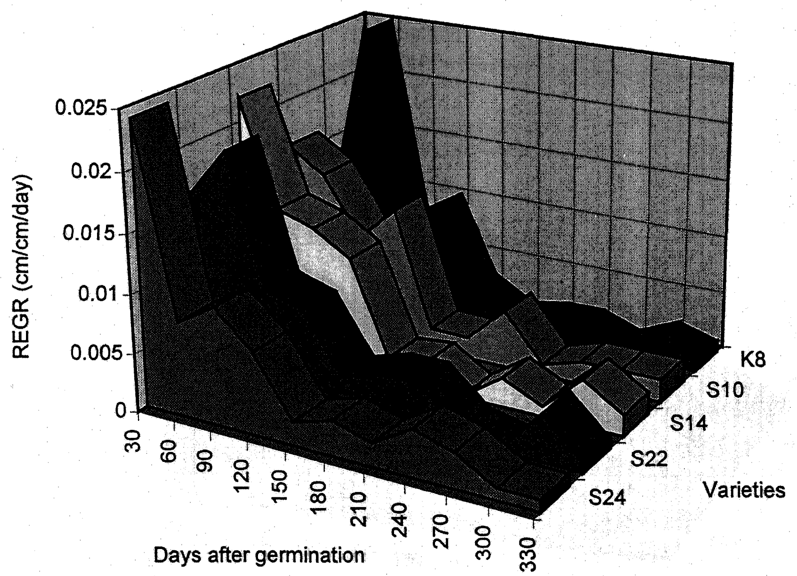


Fig. 4.1.2: Relative extension growth rate (REGR) of plant height in *L. leucocephala* varieties

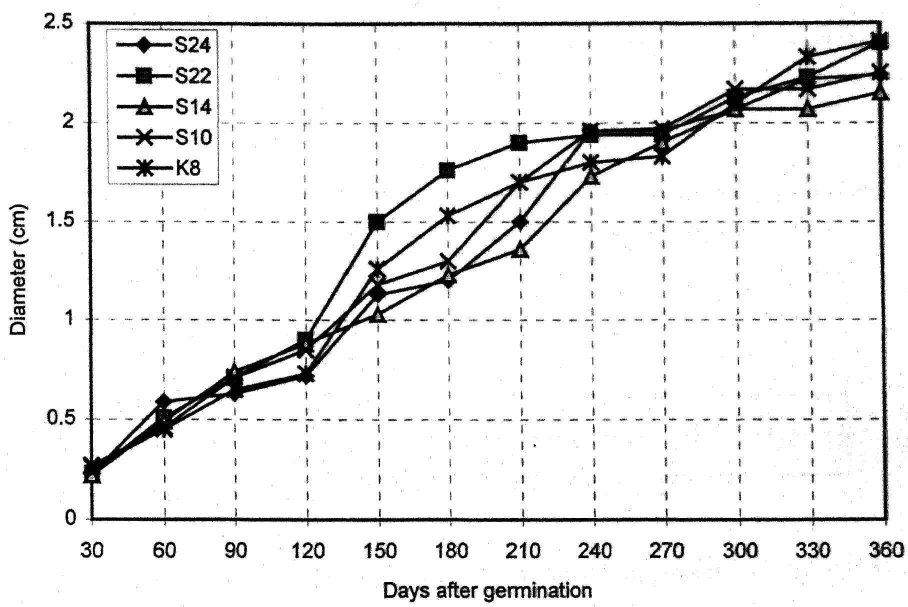


Fig. 4.1.3: Diameter growth in *Leucaena leucocephala* varieties

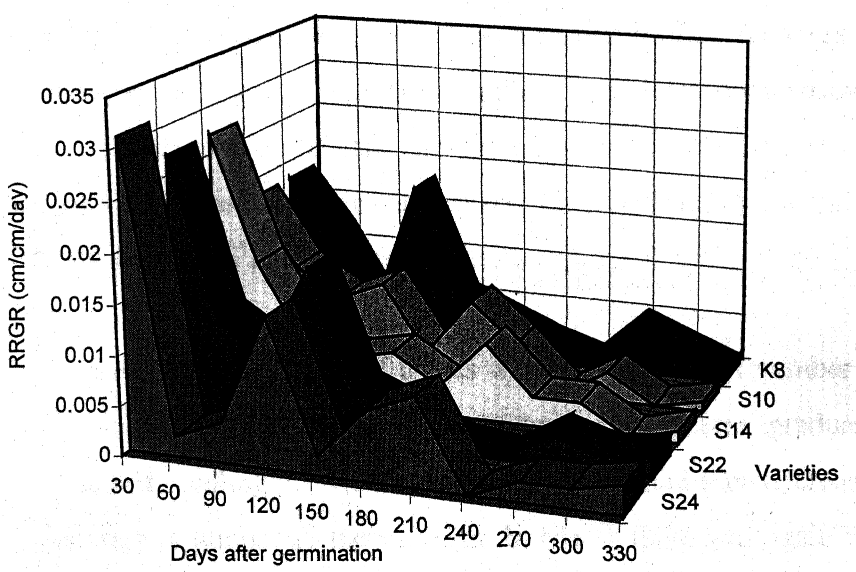


Fig. 4.1.4: Relative radial growth rate (RRGR) of diameter in *L. leucocephala* varieties

November and January to March. Variety S22 showed maximum radial growth during summer months i.e., after 300 days of growth as compared to other varieties taken.

Table 4.1.1 : Analysis of variance of plant height in *L.leucocephala* varieties during different months.

Variables	Degree of freedom	Sum of square	Mean sum of square	F value
Replication	2	3145.40	1572.7	6.613**
Varieties (V)	4	823.001	205.75	0.8651 NS
Months (M)	11	422016.991	38365.181	161.319***
V X M	44	3579.48	81.35	0.3421
Error	118	28062.872	237.821	

** Significant at 1% level, ***Significant at 0.1% level, NS - Non significant

c) Root Growth : All varieties exhibited almost similar rooting pattern (Fig. 4.1.5). The root growth in all the varieties increased upto 120 days from the date of germination. The root growth was slow in autumn which ceases during February-March. The root growth again picked up after March-April and K8 attained maximum root length followed by S14 while other varieties were at par.

d) Number of Nodules : The production of nodule with respect to their numbers in all the varieties is given in figure 4.1.6. The number of nodules continuously increased with age of seedlings upto January and decreased in February. In March the nodule production again increased but in summer months it declined. Variety S24 and S22 had produced maximum number of nodules.

e) Production of Leaves : The production of leaves with respect to their number in all the varieties is shown in figure 4.1.7. The production of leaves gradually increased upto 180 days of seedling growth i.e., up to December and then decreased during January - February in almost all the varieties. In March there was again rise in leaf production which continued up to April. During May the leaf number decreased slowly in all the varieties may be due to higher temperature during the summer. S22 produced maximum leaf number over the one year of growth as compared to the other varieties.

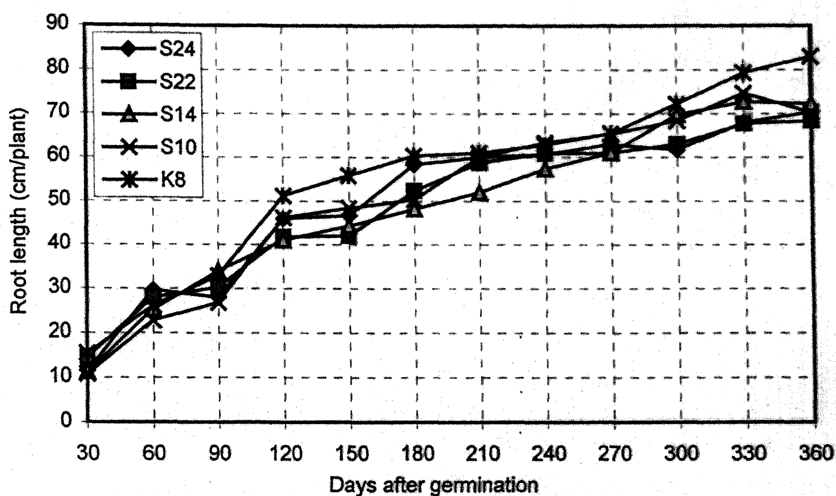


Fig. 4.1.5 : Root growth in *Leucaena leucocephala* varieties.

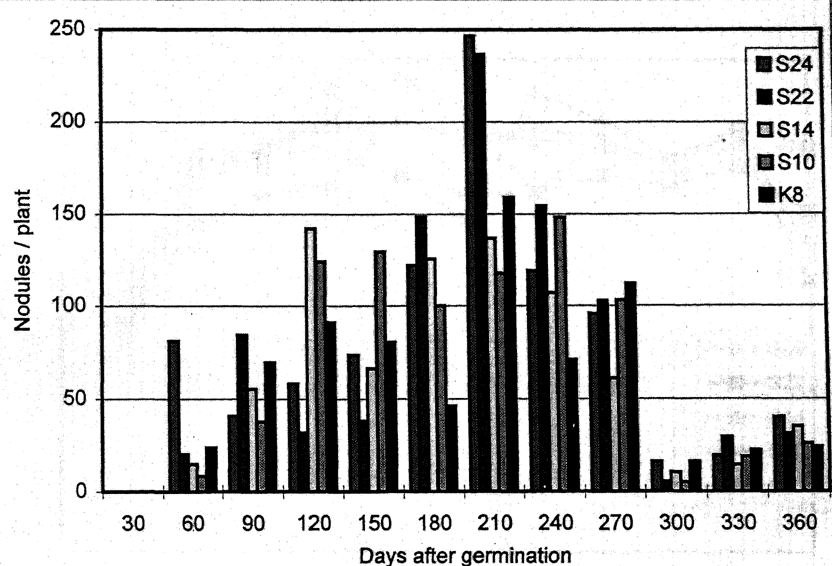


Fig. 4.1.6 : Number of nodules per plant in *Leucaena leucocephala* varieties.

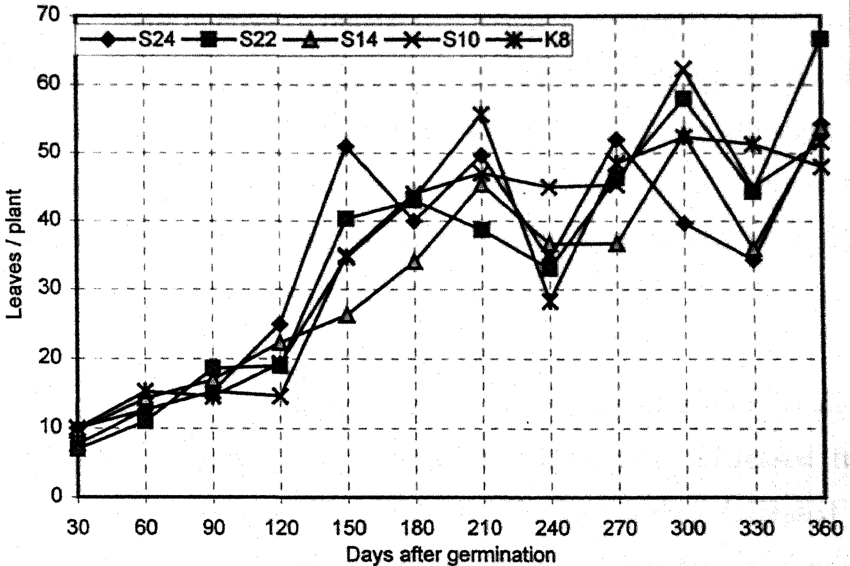


Fig. 4.1.7 : Number of leaves per plant in *Leucaena leucocephala* varieties during different months.

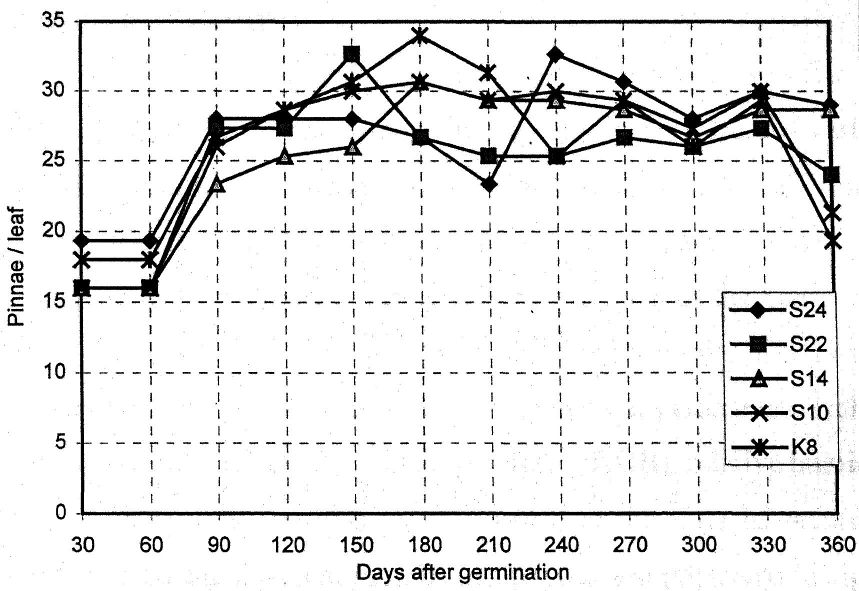


Fig. 4.1.8 : Number of pinnae per leaf during different months in *Leucaena leucocephala* varieties.

f) Number of Pinnae : The number of pinnae was found to increase gradually upto the month of November, after that these remained almost constant (Fig. 4.1.8). The production of pinnae decreased in summer months. At the early growth stage the production of pinnae was more than the later stage of growth. Variety S24 and S14 had highest number of pinnae per leaf at the end of June as compared to other varieties.

g) Number of Branches: The number of branches in one year of growth in all the five varieties is given in figure 4.1.9. The number of branches increased from September to March in all the varieties. The production of branches decreased and remained almost half in April which may be due to senescence. the formation of new branches again started with the growth flush during June - July. In the beginning variety S22 had maximum number of branches but at the end of the year of growth, variety K8 was on the top.

4.1.2 Physiological Characteristics

All the varieties were assessed throughout the growing period for carbon dioxide assimilation, transpiration, stomatal conductance, carboxylation efficiency and water use efficiency. These results are discussed as physiological and assimilatory characters of these varieties during different months of the year.

a) Microenvironmental parameters : The Microenvironmental parameters such as photosynthetically active radiation (PAR), air temperature, (TAIR), relative humidity (RH) and vapour pressure deficit (VPD) were recorded at the time of recording assimilatory parameters during different months of the year and presented in figure 4.1.10. It is apparent from the figure that photosynthetically active radiation and air temperature are lowest during December and highest during the month of June. The maximum RH was recorded in rainy season while VPD was highest in the month of May.

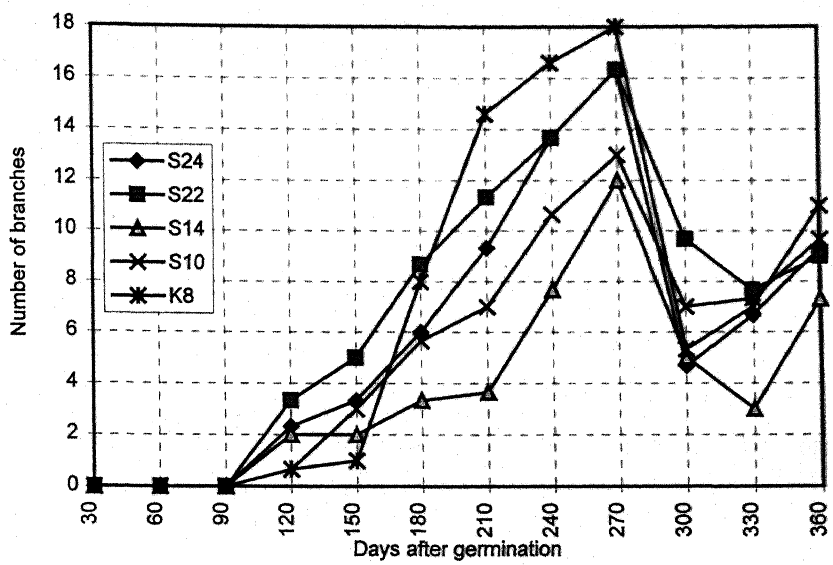


Fig. 4.1.9 : Number of branches per plant in different varieties of *Leucaena leucocephala* during the year.

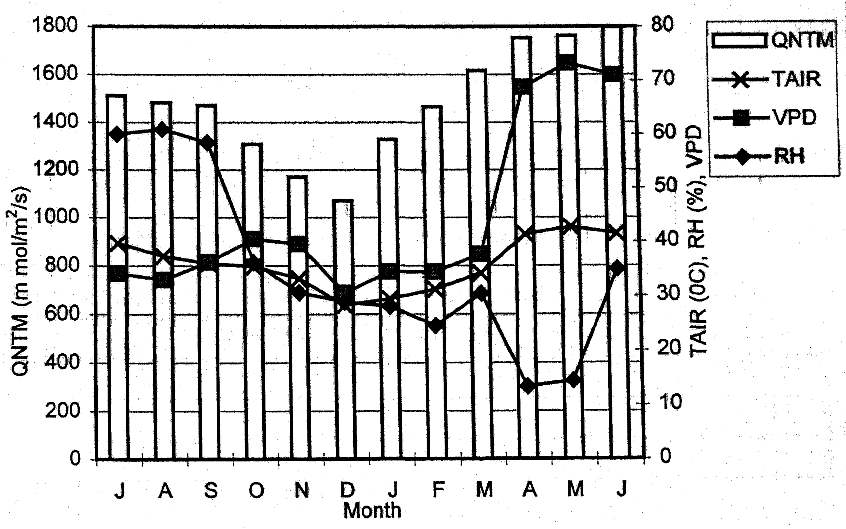


Fig. 4.1.10 : Leaf environment parameters affecting photosynthesis during different months in *Leucaena leucocephala* varieties.

b) Photosynthesis : Monthly variation in the rate of net photosynthesis (PN) in all the five varieties is given in figure 4.1.11. Maximum rate of photosynthesis was recorded in all the varieties during October and higher values were recorded in variety S24 (24.12 u mol/m^2/s) followed by S14 and S22. The lowest CO_2 assimilation rate was observed in the month of June and least values were recorded in K8 (3.54 u mol/m^2/s). In general the rate of photosynthesis (PN) was highest in rainy season, followed by autumn, declined in winter months and reached minimum in summer months in all the varieties. Over all the rate of photosynthesis was highest in variety S24 and the lowest in K8 throughout the growth period. The varietal differences were statistically significant (P>0.05).

c) Transpiration: Rate of transpiration (TR) in all the five varieties during different months of the year is shown in figure 4.1.12. Transpiration rate was found to be highest during July - October and May - June. In May, S14 and K8 exhibited its maximum water loss than the other varieties whereas minimum rate was recorded in S24 (Table 4.1.2). The steep fall in the rate of transpiration was recorded in winter months which again increased in February - March with increase in temperature in all the varieties.

Table 4.1.2 Analysis of variance of transpiration in *L. leucocephala* varieties in different months.

Variables	Degree of freedom	Sum of square	Mean sum of square	F value
Varieties (V)	4	26.552	6.638	1.918 NS
Months (M)	11	868.61	78.964	22.814***
V X M	44	193.48	4.397	1.270 NS
Error	60	207.67	3.461	

*** Significant at 0.1% level, NS - Non significant

d) Stomatal conductance : The behaviour of all the varieties with respect to the rate of stomatal conductance (CS) is given in the figure 4.1.13. Stomatal conductance is found to be highest in the month of October and lowest in the month of June in all the varieties. Maximum stomatal conductance was recorded in S24 and minimum in S10 while other two varieties (S14 and K8) were at par.

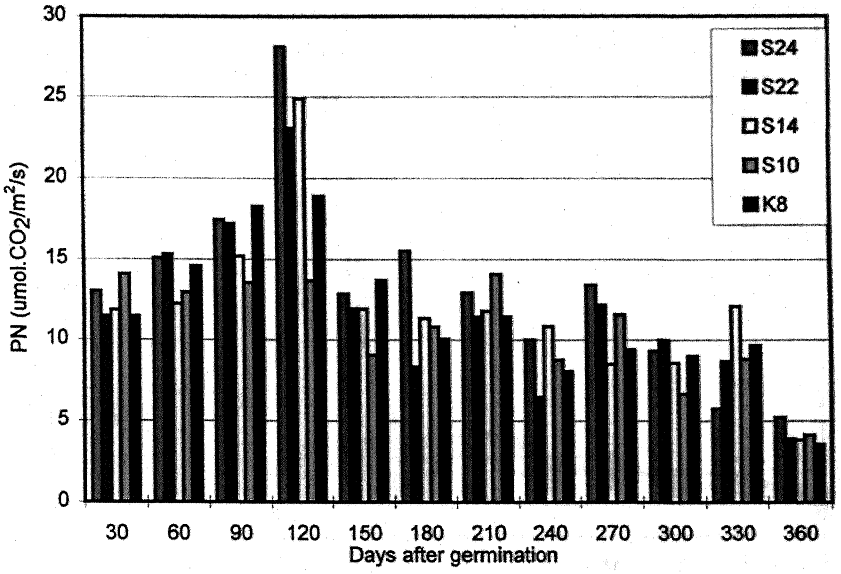


Fig. 4.1.11 : Rate of photosynthesis in *Leucaena leucocephala* varieties during different months.

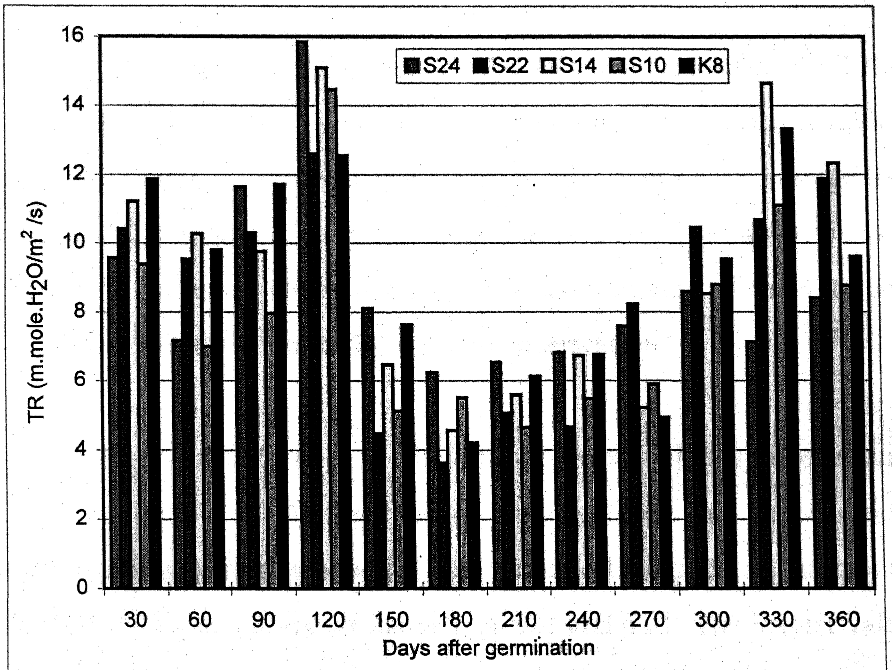


Fig. 4.1.12 : Rate of transpiration in *Leucaena leucocephala* varieties during different months.

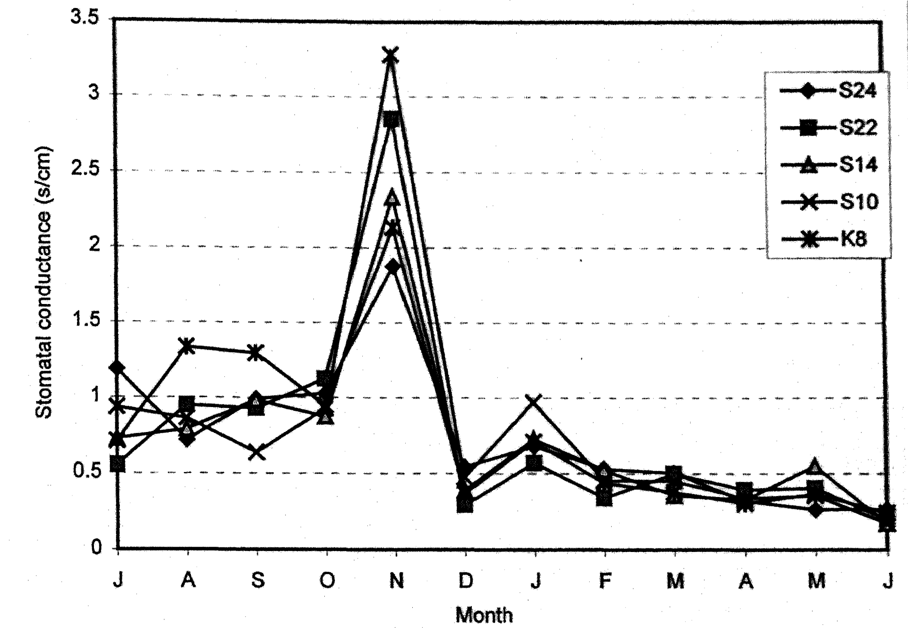


Fig. 4.13: Stomatal conductance in *L. leucocephala* varieties during different months.

e) Intercellular CO_2 concentration : The intercellular CO_2 concentration in all the five varieties is shown in table 4.1.3. No definite trend was observed in intercellular CO_2 concentration with respect to months and varieties. However on an average the highest intercellular CO_2 concentration was recorded in August, February and June differently in different varieties. On an average of twelve months, all the varieties were at par with respect to their intercellular CO_2 concentration.

f) Water use Efficiency (PN/TR ratio) : The ratio between photosynthesis and transpiration is given in table 4.1.4. The ratio of photosynthesis and transpiration (PN/TR) indicates water use efficiency which was found to be highest in the month of December in S24, S14 and K8 and in January in S22 and S10. The lowest value of PN/TR was recorded in June in all the varieties. Overall S24 and K8 indicates their higher water use efficiency followed by S10 and S22 while minimum value was observed in S14. Interaction between varieties was non significant while in the month it was significant.

Table 4.1.3 : Intercellular CO_2 concentration in *L. leucocephala* varieties during different months.

Month	VARIETY					Mean
	S24	S22	S14	S10	K8	
July	254.00	231.00	238.00	236.00	246.00	241.00
August	241.39	239.01	263.43	263.40	273.02	256.05
September	234.81	237.28	252.65	239.78	279.85	248.87
October	224.95	223.40	220.73	237.00	238.97	229.09
November	231.55	215.50	221.28	226.15	215.08	221.91
December	228.53	232.84	222.52	240.88	232.83	231.59
January	256.50	231.00	234.00	236.00	247.00	240.90
February	257.27	261.74	248.83	264.07	272.34	260.87
March	224.89	231.89	239.15	230.73	235.25	232.38
April	207.64	219.84	222.59	243.79	211.58	221.08
May	231.13	177.57	225.90	254.58	211.94	220.22
June	253.22	254.55	259.99	259.90	298.98	265.33
Mean	237.15	211.31	237.42	244.36	246.90	239.09

CD at 5% level : Variety - NS, Months - 22.82, Interaction - NS

g) Carboxylation Efficiency (PN/CINT) : Carboxylation efficiency (PN/CINT) in all the five varieties is given in table 4.1.5. The carboxylation efficiency in all the varieties increased with growth up to October and then decreased sequentially up to

Table 4.1.4 : Water use efficiency (PN/TR) in *L. leucocephala* varieties during different months.

Month	VARIETY					Mean
	S24	S22	S14	S10	K8	
July	1.36	1.08	0.94	1.665	0.945	1.198
August	2.10	1.605	1.17	1.85	1.27	1.60
September	1.555	1.675	1.56	1.70	2.375	1.773
October	1.77	1.955	1.665	0.935	1.595	1.584
November	1.625	2.03	1.85	2.29	1.795	1.918
December	2.485	2.29	2.50	2.56	2.385	2.444
January	1.855	2.46	2.05	3.03	2.12	2.303
February	1.465	1.39	1.59	1.52	1.87	1.567
March	1.775	1.44	1.68	1.44	1.905	1.648
April	1.655	0.955	1.005	0.76	1.420	1.159
May	0.825	0.895	0.80	0.75	0.915	0.837
June	0.630	0.325	0.310	0.465	0.405	0.427
Mean	1.592	1.508	1.427	1.58	1.583	1.54

CD at 5% level: Variety - NS, Months - 0.2498, Interaction - 0.558

February. This efficiency again enhanced up during March-April and finally slow down and reaches at minimum level in June. Overall highest carboxylation efficiency was observed in S24 while other varieties remained at par. Varieties and months were found statistically significant while interaction was non-significant.

4.1.3 Biomass Accumulation

a) *Fresh Weight* : Total fresh weight production per plant starting from germination till one year of growth in all varieties is shown in figure 4.1.14. The fresh weight per plant increased with age in all varieties. At the seedling stage with one month of growth variety K8 showed maximum fresh weight followed by S24 and S22 whereas after two months of growth variety S24 had higher fresh weight (10.52 g). S24 produced even higher fresh weight at 210 days of growth than other varieties but

Table 4.1.5 : Carboxylation efficiency (PN/CINT) in *L. leucocephala* varieties during different months.

Month	VARIETY					Mean
	S24	S22	S14	S10	K8	
July	0.051	0.051	0.052	0.060	0.051	0.053
August	0.064	0.069	0.061	0.056	0.077	0.069
September	0.079	0.073	0.061	0.056	0.054	0.059
October	0.124	0.104	0.104	0.095	0.105	0.106
November	0.056	0.056	0.054	0.050	0.067	0.056
December	0.068	0.046	0.051	0.053	0.049	0.053
January	0.053	0.050	0.051	0.060	0.053	0.053
February	0.039	0.025	0.038	0.034	0.038	0.034
March	0.060	0.064	0.051	0.050	0.045	0.054
April	0.059	0.045	0.044	0.043	0.044	0.047
May	0.025	0.039	0.035	0.038	0.030	0.033
June	0.021	0.015	0.015	0.017	0.012	0.016
Mean	0.058	0.053	0.051	0.054	0.052	0.053

CD at 5% level : Variety - 0.0045, Months - 0.00699, Interaction - NS

afterwards K8 accumulated the maximum fresh weight. Maximum fresh weight

(353.07 g) was recorded in K8 and variety S14 has minimum total fresh weight (280.87 g). The decrease in total biomass in S24 and S14 in summer months occurred due to lower foliage production in these species.

b) *Dry Weight* : Total biomass production per plant in terms of dry weight starting from germination till one year of age is shown in figure 4.1.15. The total dry weight was found to increase with the age of plants in all the varieties. In one month of growth K8 and S24 had maximum accumulation of dry matter and variety S14 had minimum dry weight. After one year of growth, variety K8 accumulated highest dry matter followed by S10 and S24, while other two varieties S22 and S14 were at par (Table 4.1.6). However, variety S24 showed its higher biomass accumulation during the growing season upto 180 days of growth than the other varieties. At the end of one year of growth K8, S10, S24, S22 and S14 produced 178.88, 159.59, 152.08, 145.34 and 142.36 g of dry matter per plant. The data were statistically significant.

Table 4.1.6 : Analysis of variance of total dry weight of *L. leucocephala* varieties in different months.

Variables	Degree of freedom	Sum of square	Mean sum of square	F value
Varieties (V)	4	2894.73	723.682	9.249***
Months (M)	11	499629.19	45420.84	580.49***
V X M	44	8545.52	194.22	2.482 NS
Error	120	9389.41	78.25	

***Significant at 0.1% level, NS-Non significant

c) Relative Growth Rate (RGR) : Relative growth rate in term of dry matter accumulation per unit of dry matter in all the five varieties is given in figure 4.1.16. In general all the species have shown two peaks of relative growth rate, one between July to November and another between April to May. Maximum seedling growth rate was recorded during early seedling stage and minimum in winter months which ceases during February to April. All varieties maintained almost similar pattern of relative growth rate. However, in summer months variety S24, S10 and K8 have higher relative growth rate as compared to other varieties tested.

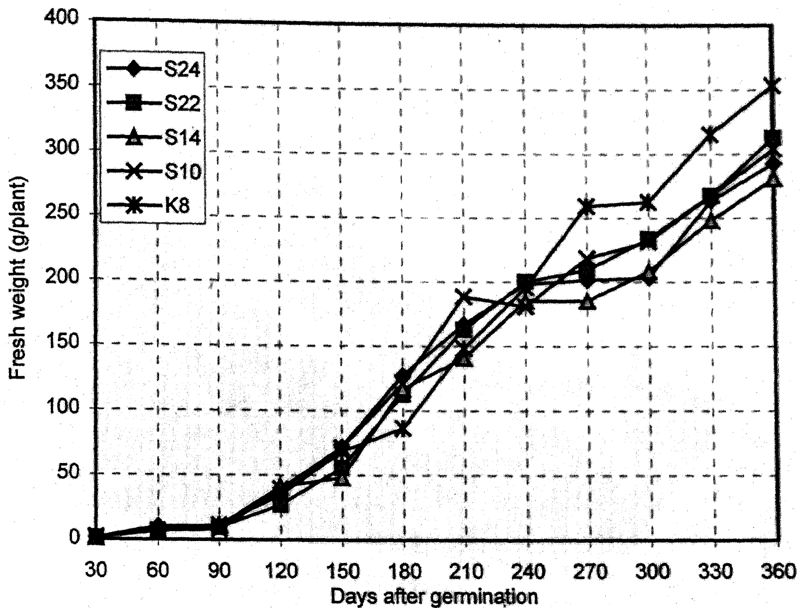


Fig. 4.1.14 : Total fresh weight produced in *Leucaena leucocephala* varieties during different months.

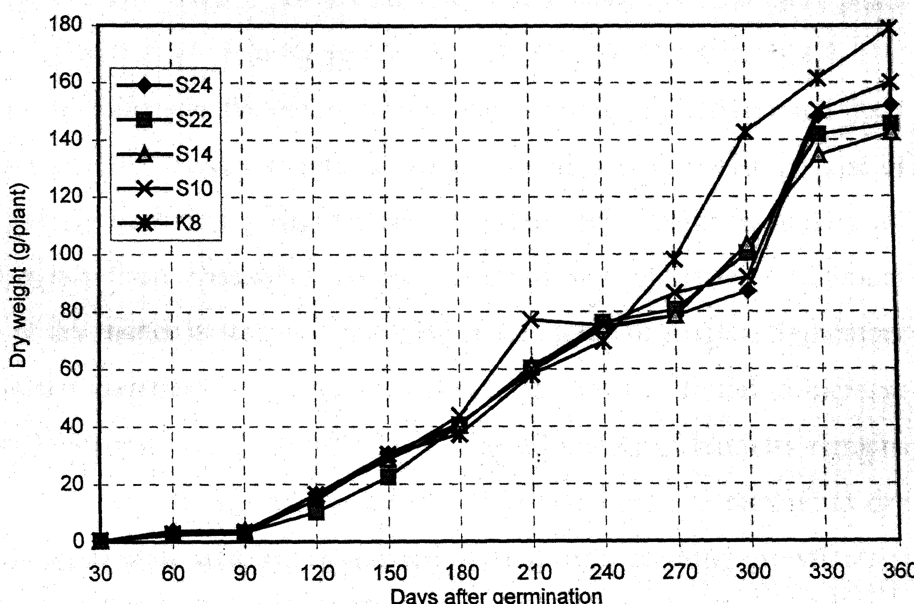


Fig. 4.1.15 : Total dry weight produced in *Leucaena leucocephala* varieties during different months.

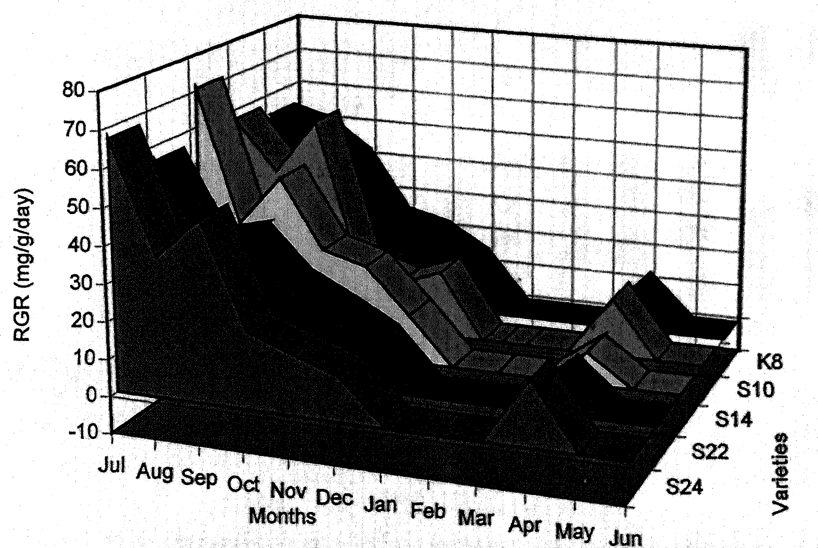


Fig. 4.1.16 : Relative growth rate (RGR) in *Leucaena leucocephala* varieties during the year.

d) Partitioning of Dry Matter : The distribution of dry matter in individual plant parts in all the varieties is given in figure 4.1.17 (A, B, C) and 4.1.18 (A, B, C). The dry matter accumulation was maximum in stem and minimum in nodules and pods in all the five varieties. The dry weight of leaves was highest at seedling stage in July. In November there was a slight increase in leaf dry weight in almost all varieties and again from December decreasing trend was observed. Maximum accumulation of dry matter in stem was recorded in the month of August, September and June in all the varieties. Dry matter partitioning to root was found to increase upto 270 days of growth i.e., in March whereas the allocation of biomass remains in equal amount in stem during this period in all the varieties. The maximum dry matter partitioning in stem and leaves was recorded at early seedling growth stage (July to October) and at the later stage of growth during May-June the partitioning of biomass was towards root. In nodules dry matter partitioning was observed maximum between August-November in all the varieties than other months. The partitioning of dry matter accumulation increases in May, June with the formation

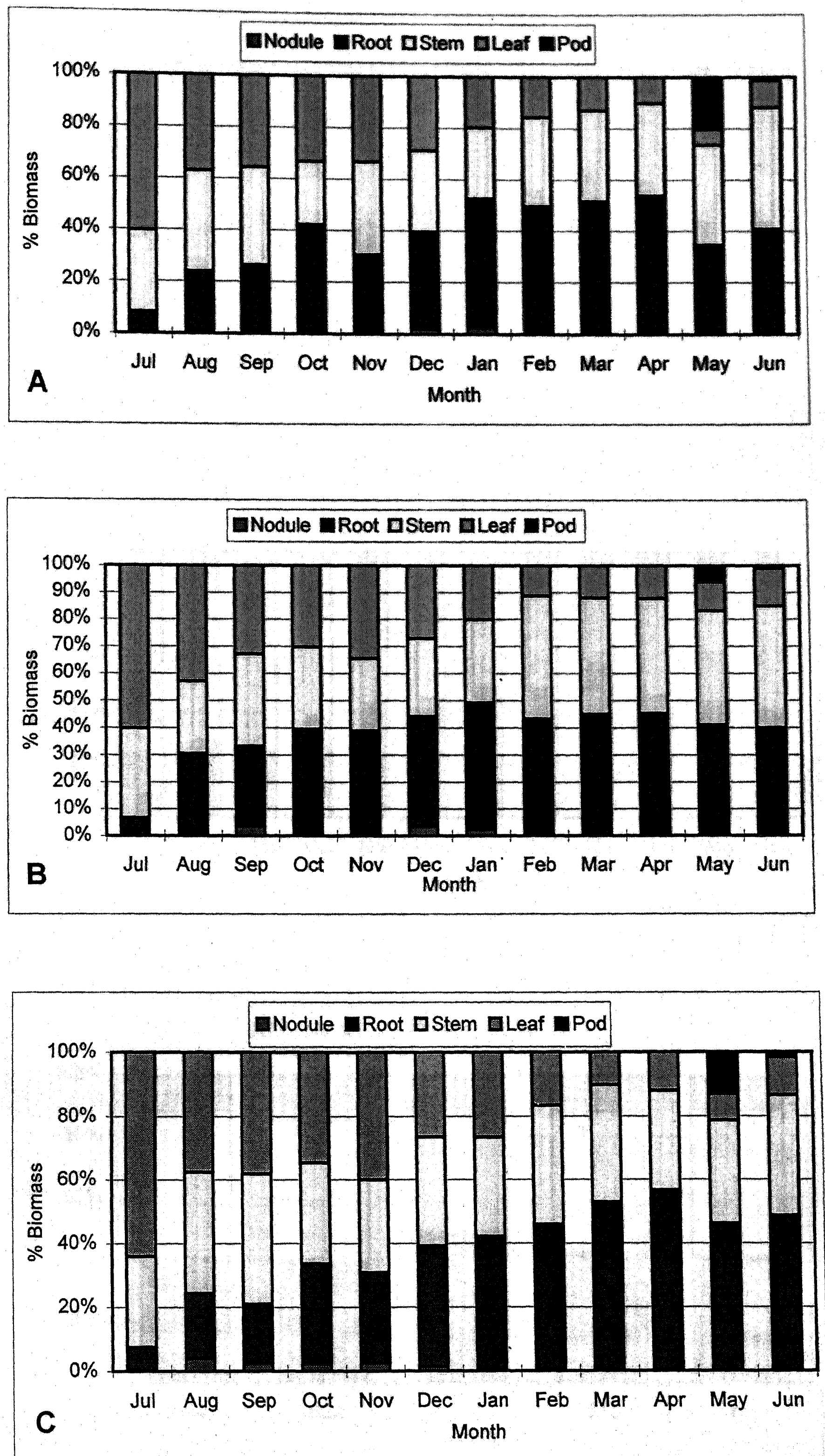


Fig. 4.1.17 : Biomass allocation in different plant parts of *Leucaena leucocephala* varieties.
(A= S24, B= S22, C= S14)

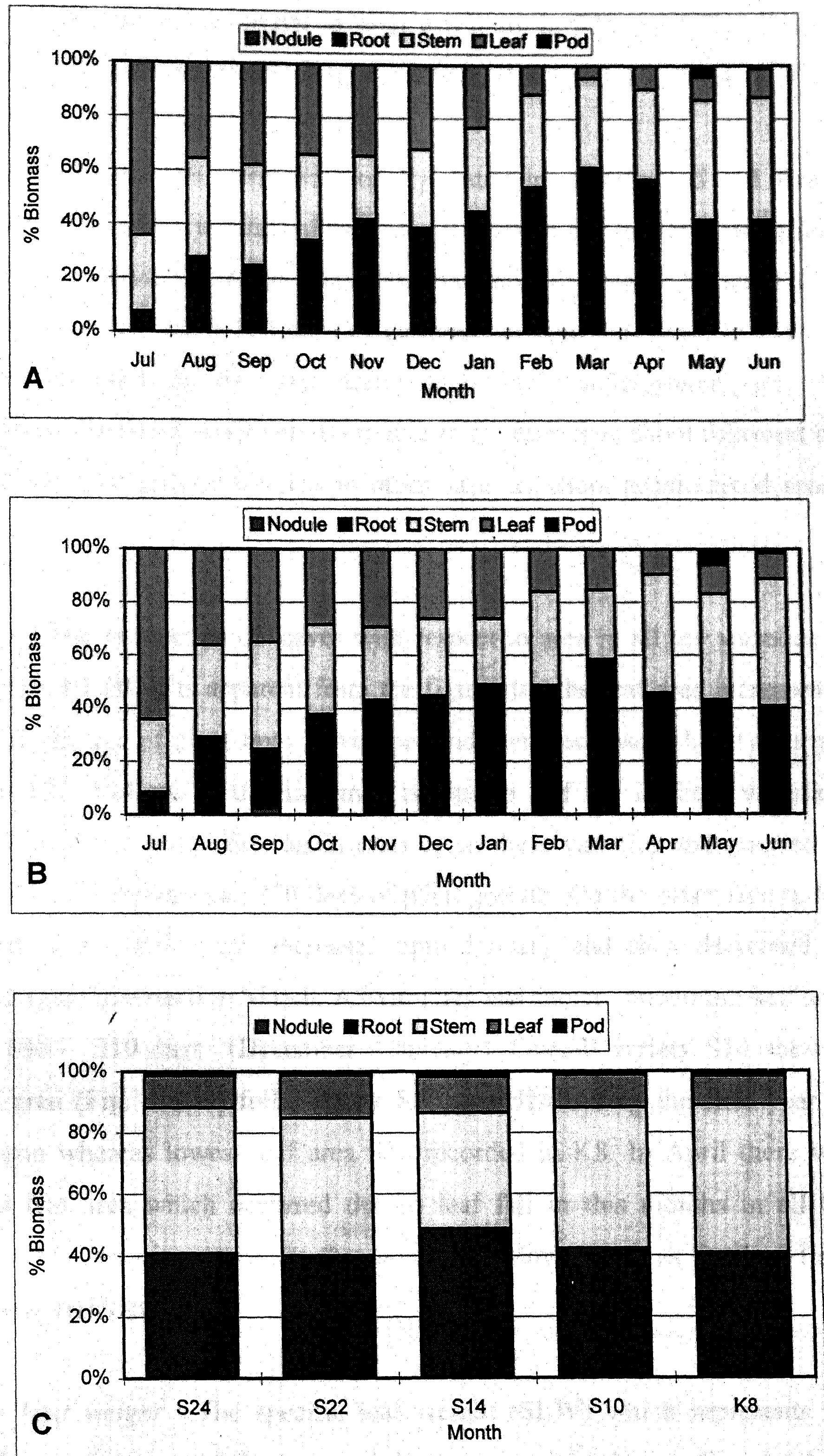


Fig. 4.1.18 : Biomass allocation in different plant parts of *Leucaena leucocephala* varieties. (A= S10, B= K8, C= Varieties at 12 months)

of pods. the partitioning of dry matter to stem was more in S24 and S22 followed by K8 and S10 as compared to S14 (Fig. 4.1.17 (A, B, C) and 4.1.18 (A, B, C).

e) Root / Shoot Ratio : The partitioning of dry matter in underground and above ground parts has been given in terms of root : shoot ratio for dry matter distribution. (Fig. 4.1.19). It is apparent from the graph that maximum dry matter accumulation was in underground part from 120 days of germination upto 300 days. In April - May there was decline in the dry matter accumulation in the underground parts. On an average K8 accumulated maximum dry matter to the root than shoot followed by S10 after 270 days of growth whereas in other varieties shoot accumulated more biomass.

f) Leaf Area : The production of leaves with respect to area in all the varieties is shown in figure 4.1.20. It is apparent from the figure that the leaf area increases gradually with the age of plant upto November and then decreased slightly during December in S22, S14 and S10 which may be due to leaf fall in these varieties. However, the leaf area production again rises up in these varieties and reached at maximum value in February i.e., 270 days of plant growth. On the other side in K8 and S22 leaf area continuously increased upto January and then decreased in February and again increased in March. All varieties had shown maximum leaf area in between 180 - 210 days (December - January). Overall variety S14 showed highest leaf area (Fig. 4.1.20) followed by S10 and S24 during the first year of growing season whereas lowest leaf area was recorded in K8. In April there was sharp fall in leaf area which occurred due to leaf fall in this months in all the varieties. The leaf area increases in the months of May - June as the leaf flush started in these varieties.

g) Specific Leaf weight : The specific leaf weight (SLW) which represents the average leaf dry weight per unit leaf area of all the varieties is given in figure 4.1.21. On an average the specific leaf weight increased upto December with the growth of

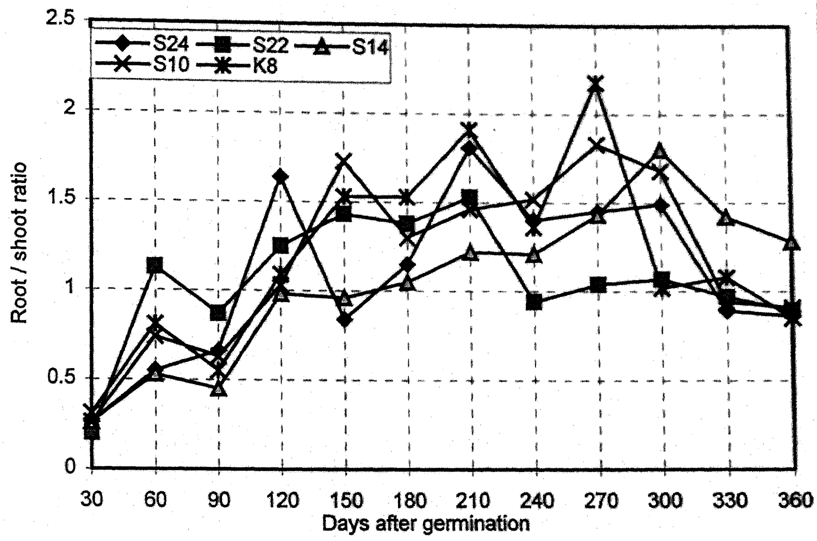


Fig. 4.1.19 : Root / shoot ratio in *Leucaena leucocephala* varieties during different months.

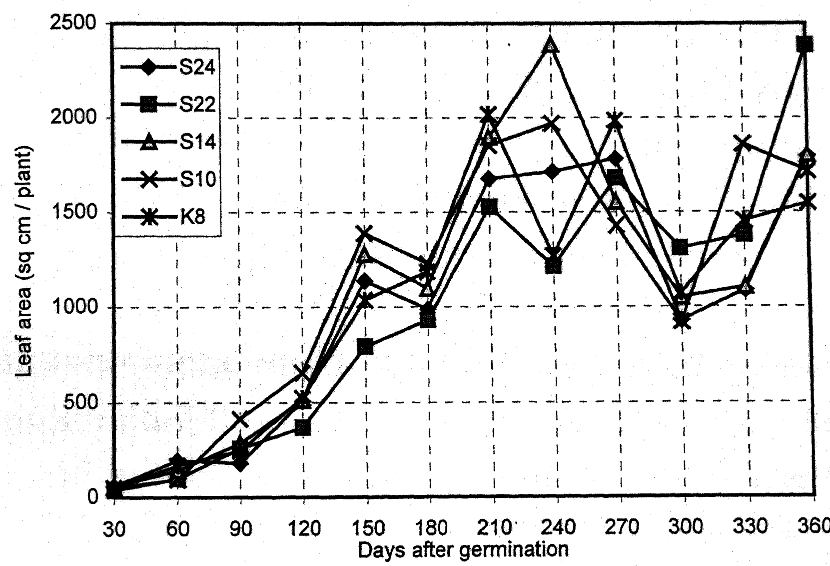


Fig. 4.1.20 : Leaf area changes in *Leucaena leucocephala* varieties during different months.

plants in all the varieties and then decreased sharply and reached at minimum level in February - March. All the varieties again achieved higher SLW in summer months. In the winter growth stage during December - January all the selections showed maximum SLW than K8.

h) Specific Leaf Area : Specific leaf area (SLA) which represents unit leaf area per leaf dry weight is given in figure 4.1.22. Specific leaf area was observed maximum at early seedling growth and minimum at full leaf growth in the month of December. The increasing SLA was also recorded from January to March which again fell down in April. However, no definite trend was seen with respect to varietal difference in their characters.

i) Leaf Weight Ratio : Leaf weight ratio (LWR) represents the fraction of the total dry weight to be present in leaf and is shown in figure 4.1.23. The leaf weight ratio decreased upto 120 days of growth (October) which again increased in between (120 - 150 days) i.e., October - November. After attaining full leaf growth, the partitioning of biomass to leaf decreased and by which the LWR gradually decreased and reached at minimum level in summer months. Over all the selections were having high LWR as compared to K8. This fall in leaf weight ratio indicates the decrease in dry weight partitioning in the leaves with increasing plant age.

j) Leaf Area Ratio : The leaf area ratio (LAR) which is a ratio of leaf area and total dry weight is basically a morphological index of the proportion of the assimilatory surface to the total dry matter. Leaf area ratio of all the five varieties from germination to one year of growth is given in figure 4.1.24. Leaf area ratio was maximum at the seedling stage which gradually falls down and reached at minimum value in the month of December. The sharp rise in leaf area ratio was again noticed in February - March in all the varieties. The decrease in leaf area exhibits that the respiratory mass is increasing more than the assimilatory surface area.

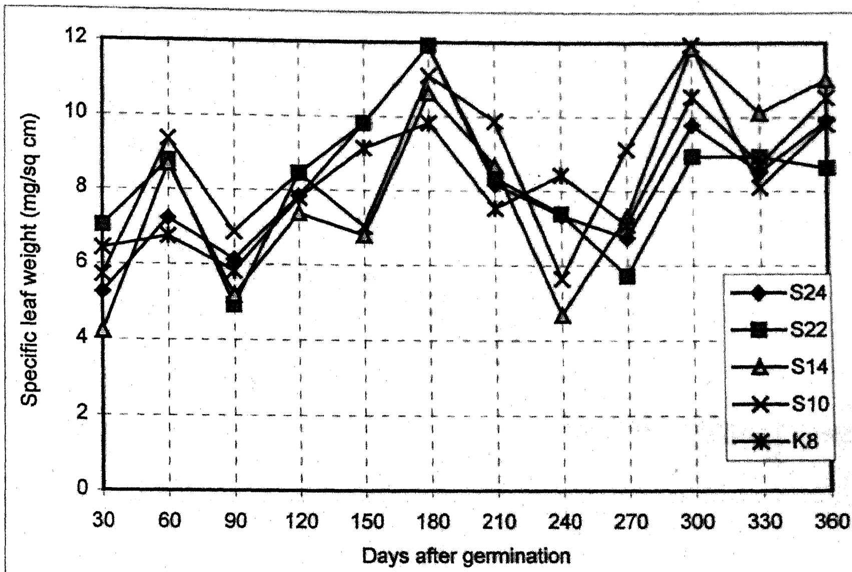


Fig. 4.1.21 : Specific leaf weight in *Leucaena leucocephala* varieties during the year

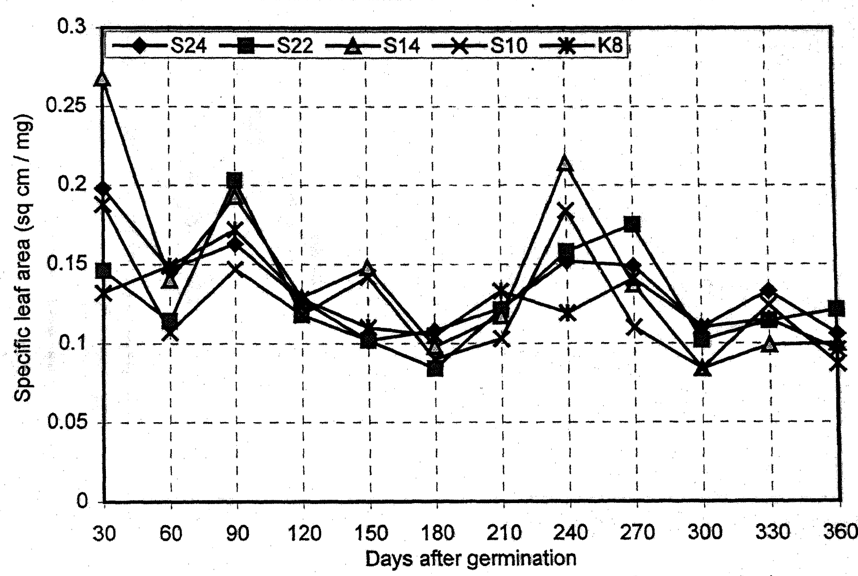


Fig. 4.1. 22 : Specific leaf area in *Leucaena leucocephala* varieties during the year.

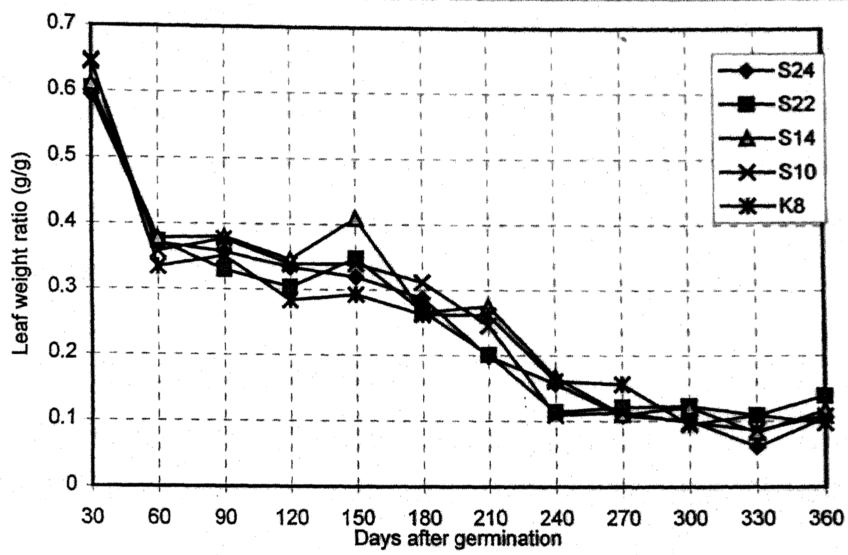


Fig. 4.1.23 : Leaf weight ratio in *Leucaena leucocephala* varieties during different months.

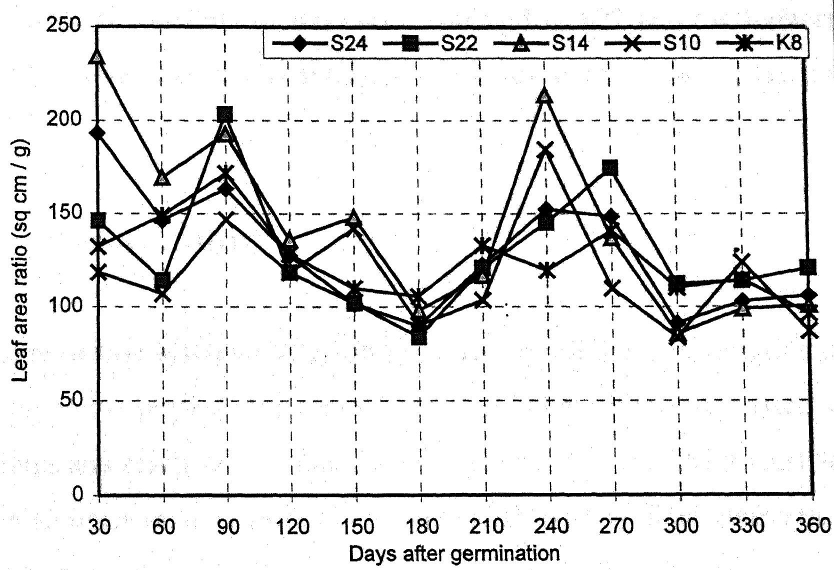


Fig. 4.1.24 : leaf area ratio in *Leucaena leucocephala* varieties during different months.

4.1.4 Photosynthetic Pigments

Seasonal variations in photosynthetic pigments (chl a, chl b, chl a + b and chl a : b) were estimated in all the five varieties of *Leucaena leucocephala* and presented in table 4.1.7. In general all the varieties accumulated maximum chlorophyll a and b during seedling stage in September and December and minimum in June. Similarly total chlorophyll and chlorophyll a : b ratio was found to be maximum during seedling stage upto September which decreases as leaf become older in March. The accumulation of chlorophyll slightly increased in some varieties which may be due to emergence of new leaves during this period. Overall the selections showed higher photosynthetic efficiency as indicated by their higher chl a : b ratio than K8. Variety, season and their interactions were found to be significant (P>0.05) in case of chl a and chl b while chl a : b was significant at seasonal level.

Accumulation of carotene content was estimated in all the seasons (Table 4.1.8). On an average the lowest carotene was estimated in S22 and the highest in S10. Carotene content was statistically significant with respect to variety, season and in their interactions.

4.1.5 Nitrate Reductase Activity

Nitrate reductase activity (NRA) in the leaves of all the five varieties were studied seasonally and is presented in table 4.1.9. The NRA activity increased with growth of seedlings and reached at its maximum level upto March. The lowest NRA was estimated in summer months (June) in all the varieties. The maximum value of NRA was observed in S14 (1237.27 m u mol NO_2/g F wt/hr) during March. However, on an average all the selections were at par with respect to their NRA. Seasonal influence was found statistically significant.

Table 4.1.7 : Chlorophyll a and b content in *L. leucocephala* varieties during different seasons.

Month	VARIETY						Mean
	Chlorophyll	S24	S22	S14	S10	K8	
September	a	0.498	0.474	0.863	0.888	0.823	0.709
	b	0.158	0.131	0.242	0.293	0.229	0.210
	a+b	0.656	0.605	1.105	1.192	1.051	0.922
	a:b	3.125	3.618	3.566	3.594	3.594	3.500
December	a	0.622	0.578	0.603	0.72	0.642	0.633
	b	0.251	0.229	0.227	0.278	0.250	0.247
	a+b	0.873	0.807	0.83	1.021	0.891	0.884
	a:b	2.478	2.524	2.656	2.589	2.568	2.563
March	a	0.529	0.329	0.523	0.427	0.385	0.439
	b	0.236	0.105	0.143	0.102	0.165	0.150
	a+b	0.765	0.424	0.663	0.529	0.55	0.586
	a:b	2.750	3.410	3.700	4.500	2.33	3.340
June	a	0.448	0.444	0.401	0.498	0.497	0.458
	b	0.19	0.148	0.135	0.175	0.193	0.168
	a+b	0.638	0.592	0.535	0.673	0.69	0.665
	a:b	3.0	3.0	2.97	2.845	2.575	2.880
Grand Mean	a	0.524	0.456	0.597	0.633	0.586	0.558
	b	0.246	0.153	0.187	0.212	0.209	0.201
	a+b	0.733	0.607	0.783	0.854	0.795	0.754
	a:b	2.838	3.140	3.220	3.380	2.763	3.070

		Chl a	Chl b	Chl a+b	Chl a : b
CD at 5%	Variety	0.0867	0.143	0.119	NS
	Months	0.0776	0.0403	0.107	0.63
	Interaction	0.1735	0.09	0.2382	NS

Table 4.1.8: Carotene content in *L.leucocephala* varieties during different months of the season.

Month	VARIETY					Mean
	S24	S22	S14	S10	K8	
September	0.378	0.383	0.51	0.523	0.461	0.451
December	0.451	0.382	0.401	0.525	0.54	0.459
March	0.431	0.366	0.455	0.35	0.300	0.38
June	0.348	0.335	0.32	0.392	0.349	0.348
Mean	0.402	0.366	0.421	0.447	0.412	0.410

CD at 5% level: Variety - 0.043, Months - 0.039, Interaction - 0.0867

Table 4.1.9 : Nitrate reductase activity **(m u mol NO_2/g F wt/hr) in *L.leucocephala* varieties during** different seasons.

Month	VARIETY					Mean
	S24	S22	S14	S10	K8	
September	332.75	246.53	225.12	318.865	509.84	326.622
December	842.02	839.12	786.455	777.78	922.45	833.566
March	997.665	1197.91	1237.27	1101.85	1117.48	1130.436
June	229.75	212.965	233.22	219.33	276.625	234.378
Mean	600.548	624.133	620.516	604.456	706.60	631.251

CD at 5% level : Variety - NS, Months - 252.81, ·Interaction - NS

4.1.6 Carbohydrate Content

a) Sugar Content : Seasonal variation in the sugar content in different parts of all the varieties is given in table 4.1.10. The accumulation of sugar content in leaves increased with the growth of the leaves up to March in all the varieties. Although no significant difference was observed among the varieties in sugar content in leaves but slightly higher sugar content was estimated in S10. Seasonal effects on sugar accumulation in leaves were more prominent as indicated by level of significance at P>0.05.

The maximum accumulation of sugar content in stem with respect to season was found in varieties S10 and S14 while S22, and S24 were at par and the minimum content was in variety K8. The sugar content in stem increased with age of the plant and reached maximum level after 180 days of growth (December) and maintained its higher level up to March which then declined in the summer months. Season and interactions of the varieties and season were statistically significant. Maximum sugar content in roots was found in variety S24 followed by S22, S14 S10 and minimum was in K8.

Similar to leaf and stems the sugar accumulation in roots increased with growth of roots and maximum level was estimated in December to March. In summer months the roots maintained higher level of sugar content while it was at its minimum during the growing season in the month of July to September. Role of variety and season were found statistically significant (P>0.05).

b) Starch Content : The starch content in leaves increased with growth of leaves and maximum content was estimated in March whereas minimum at early seedling stage (Table 4.1.11). However, the starch content in leaves was equal in December and June. The maximum starch content in leaves was found in variety K8 and S10 while it was at par in the other varieties. In stem and roots the starch accumulation increased continuously with increase in growth and reached at its maximum level in summer months. The maximum starch content in stem and roots was recorded in S24, S22 and S14. Where as it was at equal level in S10 and K8. Seasons and its interactions with variety were analyzed statistically significant.

4.1.7 Crude Protein Content

Seasonal variation in the crude protein content in different parts of all the varieties are presented in table 4.1.12. In the beginning the accumulation of crude protein was maximum which decreased upto the March in all the varieties. Although no significant variation was observed for crude protein content between different varieties but the leaves of S14 had maximum crude protein content. The accumulation of crude protein in the stem was found to increase with the age of the plant. The maximum value has been obtained in S24 and minimum in K8. Variety wise variations were not found to be significant. The accumulation of crude protein in roots increased in the beginning but showed decline in March and again increase in June. Maximum value was obtained in variety K8.

4.1.8 Discussion

The growth behaviour of all the five varieties of *Leucaena leucocephala* during first year of growth indicates that maximum growth in terms of the height increment was from July to October. The spurt in the rates of relative extensiongrowth was found to be highest at seedling stage (between July-November) in all the varieties and again from March to May (Table 4.1.13). However, the magnitude of relative growth rate was very low at the later stage of growth. The cessation of growth of relative growth in all the varieties occurred during winter months as exhibited by lower REG.

Table 4.1.10 : Sugar percentage in plant parts of *L.leucocephala* during different months.

Month	Plant part	VARIETY					Mean
		S24	S22	S14	S10	K8	
September	Leaf	4.5	5.15	4.87	5.40	5.15	5.014
	Stem	8.2	6.75	7.85	7.35	7.20	7.47
	Root	4.85	4.90	4.975	5.15	4.85	4.941
December	Leaf	5.55	5.65	5.10	5.45	5.60	5.47
	Stem	7.60	8.85	8.75	9.05	8.35	8.52
	Root	6.80	6.65	6.90	6.35	6.35	6.61
March	Leaf	6.75	6.40	6.55	6.975	6.75	6.685
	Stem	8.25	8.45	8.15	8.20	7.70	8.15
	Root	7.10	6.96	6.77	6.70	6.55	6.82
June	Leaf	5.95	5.51	5.27	5.465	5.55	5.549
	Stem	7.35	7.45	7.60	7.55	7.55	7.50
	Root	7.275	7.15	7.03	7.00	7.04	7.099
Mean	Leaf	5.688	5.678	5.448	5.823	5.763	5.68
	Stem	7.85	7.875	8.088	8.038	7.700	7.91
	Root	6.506	6.41	6.42	6.30	6.19	6.367

		Leaf	Stem	Root
CD at 5% level	Variety	NS	NS	0.204
	Months	0.0369	0.34	0.182
	Interaction	NS	0.759	NS

The phenometry of *Leucaena* varieties clearly indicates two maximum recurrent growth flushes in the one year of growth keeping in view the relationship between maximum and minimum air temperature and plant height. It was observed that plant height is positively correlated with maximum air temperature and negatively with minimum air temperature (Table 4.1.13) .

The magnitudes of dependence of plant height increment on the air temperature were slightly linear as indicated by the values of correlation coefficient. However it is apparent that maximum air temperature favours the growth of all the varieties. On an average, extension growth was found to be maximum in S10 (0.5 cm day) and lowest in variety K8 (0.48 cm/day) whereas the extension growth was equal (0.49 cm/day) in S24, S22 and S14. A total magnitude of plant height growth during the annual growth cycle seems to be strongly dependent on leaf number and leaf area as it is evident from the correlation values. This higher correlation between leaf area and extension growth was also reported by various workers (EI. Sharkaway *et al.* 1965, Duncan and Hesketh 1968 and Hanson 1972).

Table 4.1.11 : Starch accumulation (%) in **plant parts of *L.leucocephala* during different months.**

Month	Plant part	VARIETY					Mean
		S24	S22	S14	S10	K8	
September	Leaf	5.4	5.7	5.56	5.9	5.8	5.67
	Stem	5.45	5.37	5.15	5.41	5.45	5.36
	Root	5.05	5.1	5.13	5.25	5.32	5.17
December	Leaf	6.3	6.2	6.57	6.45	6.11	6.33
	Stem	6.4	6.75	7.4	6.5	6.45	6.7
	Root	7.05	7.10	7.35	6.85	6.45	6.96
March	Leaf	7.15	6.9	6.7	7.04	7.25	7.00
	Stem	7.4	7.45	7.4	7.15	7.26	7.33
	Root	7.45	7.1	6.98	6.9	6.75	7.04
June	Leaf	6.1	6.26	6.5	6.40	6.65	6.38
	Stem	7.7	7.55	7.03	7.25	7.17	7.34
	Root	7.4	7.3	7.43	7.25	7.7	7.41
Mean	Leaf	6.24	6.26	6.33	6.448	6.45	6.34
	Stem	6.74	6.78	6.74	6.58	6.58	6.68
	Root	6.74	6.65	6.72	6.56	6.563	6.64

		Leaf	Stem	Root
Cd at 5% level :	Variety	NS	NS	NS
	Months	0.246	0.213	0.223
	Interaction	NS	0.477	0.499

The radial growth in terms of basal stem diameter showed peak growth in the month of November and again during January to March. On an average the growth of stem diameter of K8 and S24 exceeds to those of S10 and S14 (Table 4.1.4). Variety S22 showed 5.1 cm comparatively highest radial growth than other varieties. Similar to the plant height, the radial growth is positively correlated with maximum air temperature and negative with minimum air temperature (Table 4.1.14).

The radial growth of all the varieties is positively correlated with plant height, leaf number and leaf area and as well as root elongation. These results are similar to the findings of Bhatt (1990). It has been reported by various workers that the radial growth is influences by light intensity, temperature, water supply and soil fertility (Kozlowski 1971, Kramer and Kozlowski 1960). Thus from wood production point of view S24, S22 and K8 are superior than S14 and S10 (Table 4.1.13).

Table 4.1.12 : Crude protein content in *Leucaena leucocephala* varieties during different seasons.

Month	VARIETY						Mean
	Parts	S24	S22	S14	S10	K8	
September	Leaf	23.58	21.9	24.16	23.0	26.72	23.87
	Stem	6.68	6.89	8.77	5.69	5.91	6.79
	Root	10.14	8.66	6.03	8.33	9.71	8.63
December	leaf	22.33	21.79	28.1	22.91	25.16	24.06
	Stem	6.57	7.02	7.77	11.29	5.43	8.93
	Root	13.99	11.68	11.67	11.85	12.21	12.28
March	Root	16.63	16.86	18.04	17.29	17.07	17.18
	Stem	10.83	7.37	8.43	6.75	7.88	8.25
	Root	11.07	9.69	10.46	9.45	11.07	10.35
June	Leaf	20.89	19.59	24.78	22.76	20.93	21.79
	Stem	15.8	12.78	12.74	9.6	11.56	12.5
	Root	13.57	11.91	12.76	16.16	15.52	11.98
Mean	Leaf	20.86	20.04	23.77	21.49	22.47	21.73
	Stem	9.97	8.52	9.43	8.33	7.70	9.12
	Root	12.19	10.49	10.23	11.45	12.29	10.81

Table 4.1.13 : Average plant productivity per day in *Leucaena leucocephala* varieties.

Characters	VARIETY				
	S24	S22	S14	S10	K8
Plant height (cm/day)	0.49	0.49	0.49	0.50	0.48
Stem diameter (mm/day)	0.62	0.67	0.60	0.56	0.67
Root length (cm/day)	0.20	0.19	0.20	0.19	0.23
Leaf number / day	0.15	0.18	0.15	0.14	0.13
Total dry weight (g/day)	0.42	0.40	0.39	0.44	0.50
RGR (mg/g/day)	18.36	16.58	19.17	18.96	16.39
PN (mg/m^2/day)	25128.6	22163.04	22657.56	20281.56	21783.12
TR (mmole/m^2/day)	372816.0	365472.0	397094.0	336096.0	384912.0

Table 4.1.14: Correlation coefficient between maximum and minimum atmospheric temperature, photosynthetically active radiation and other growth parameters in *Leucaena leucocephala* varieties.

Temperature / PAR	Characters	VARIETY				
		S24	S22	S14	S10	K8
Maximum temperature	Plant height	0.2717	0.1811	0.1520	0.2156	0.1166
	Dry weight	0.4857	0.4841	0.4427	0.3097	0.5528
	Diameter	0.2692	0.1086	0.3176	0.1983	0.2267
	Leaf Number	0.1640	0.2356	0.1039	0.0487	0.1163
	Leaf area	- 0.0002	-0.1633	- 0.03003	- 0.1810	- 0.1367
	REG	0.02148	0.0240	-0.0320	0.0042	-0.0107
	RGR	0.1012	0.1463	0.0020	0.0467	0.0277
Minimum temperature	Plant height	- 0.1117	- 0.1884	- 0.2107	- 0.1494	- 0.2691
	Dry weight	0.2053	0.2259	0.1915	0.1655	0.2724
	Diameter	- 0.0683	- 0.2367	- 0.0304	- 0.1617	- 0.0986
	Leaf Number	- 0.1857	- 0.0983	- 0.1722	- 0.2918	- 0.2348
	Leaf area	- 0.3494	- 0.0779	- 0.4975	- 0.4440	- 0.4210
	REG	0.3391	0.3240	0.3624	0.35004	0.3441
	RGR	0.2024	0.2429	0.2478	0.2396	0.2240
PAR	Plant height	0.1122	0.3102	0.3718	0.0602	-0.0632
	Dry weight	0.23045	0.3791	0.3662	0.2596	0.3404
	Diameter	0.2454	0.2693	0.2849	0.1707	0.1226
	Leaf number	-0.06561	-0.1052	0.4061	0.0650	0.1011
	Leaf area	-0.0559	-0.0769	-0.3229	-0.1666	-0.0301
	REG	-0.0306	-0.0523	-0.0590	0.1189	0.3782
	RGR	0.03926	0.1629	0.1743	0.05004	0.0686

The maximum elongation of roots in annual growth cycle was found in K8 followed by S14 while S24 and S10 were equal in root elongation. The root growth of all the varieties of *Leucaena leucocephala* synchronized with the shoot elongation as is apparent from the extension growth curves of plant height and root length. The

root length was found to show positive correlation with maximum air temperature (Table 4.1.14). This trend can be related to the limited root growth during summer months (Fernandez and Caldwell 1975, Jorden and Nobel 1984). Root length was also found to be strongly correlated with plant height, diameter and number of leaves. These results are confirmatory to the findings of Vandana (1996) in *S. Sesban* and *S. grandiflora*.

The nodule production with respect to their number was found to increase with the growth of plants in all varieties up to December-January and then decreased in February due to onset of dormancy. It is apparent that nodule production was lowest during winter season and as the temperature rises their production increases. This shows the dependency of nodule production on seasonal growth of plants.

The leaf turnover rate (the number of leaves produced per day) is the key of fodder production in a plant variety. On an average maximum leaf production per day was found in variety S22 (Fig. 4.1.13) and minimum in variety K8 while other varieties were at par in their leaf production. The leaf number was found to be positively correlated with the maximum air temperature and negative with minimum air temperature (Table 4.1.14) indicating its dependence on seasonal temperature and this is the reason of low production of leaves during winter season (Harper 1989). The number of leaves were found to increase with the age of plant or with the shoot elongation as was reported by (Longman and Jenik 1974). The leaf number is strongly correlated with all the morphological characters supporting its contribution in overall productivity of plant (Table 4.1.17 a,b,c,d,e). The higher leaf turnover rate in S22, S24, and S14 indicates their higher fodder production then S10 and K8. The number of pinnae was also found to increase up to November and as the temperature fell the number of pinnae remained constant. The maximum production of pinnae per leaf was in S24 and S14 indicating their higher forage biomass production potential as compared to other varieties.

The production of branches in all the varieties were found to increase with the growth of plants and reached at highest number in March. The decrease occurred due to senescence of branches at this stage of growth in *Leucaena leucocephala* varieties. The production of branches again occurred with their growth flush in May-

June. The average branch production was found to be highest in variety K8 which led to its higher biomass production as is evident by its strong correlation with plant height, diameter, the number of leaves and biomass production (Table 4.1.17 a,b,c,d,e).

Table 4.1.15 : Correlation coefficient between dry weight and other growth parameters in *Leucaena leucocephala* varieties.

Characters	VARIETY				
	S24	S22	S14	S10	K8
Plant height	0.9225	0.8928	0.8907	0.9148	0.8315
Leaf number	0.8074	0.8471	0.8601	0.8033	0.7893
Leaf area	0.7245	0.8765	0.6429	0.7698	0.6569
SLW	0.5523	- 0.1214	0.6162	0.3408	0.6765
Dry wt. vs					
Root length	0.8561	0.8660	0.9246	0.8572	0.7669
Nodules	- 0.1001	- 0.0420	- 0.1774	- 0.0933	- 0.1946
Chl a+ b	- 0.2011	- 0.3179	- 0.4109	- 0.3461	- 0.3934
Chl a : b	0.2145	0.1189	- 0.0674	0.3405	- 0.2616
PN/TR	- 0.6571	- 0.6297	- 0.4818	- 0.4731	- 0.5073
PN/CINT	- 0.6110	- 0.2465	- 0.6906	- 0.6808	- 0.7139

The rate of photosynthesis (PN) per unit leaf area and time in all varieties of *Leucaena leucocephala* was highest in rainy season and lowest in summer months. The decrease in the rate of photosynthesis with increasing age of seedlings may be due to age effect on the uptake of CO_2 as reported by Ledig *et al.* (1977) and Sestak (1981). Among all the varieties, maximum rate of CO_2 assimilation was observed in S24 indicating its higher photosynthetic efficiency in the semi arid environment.

The rise in photosynthetic rate during rainy season was accompanied by higher stomatal conductance, optimum level of PAR and temperature. The decline in PN during summer may be due to high temperature and low relative humidity as also reported by (Stain *et al.* 1976, Bhatt 1989). Rate of photosynthesis is positively correlated with stomatal conductance and transpiration which shows

interdependencies of these characters. A weak and negative correlation was analyzed between photosynthetic rate and dry weight (Table 4.1.16) as was reported by Ledig and Perry (1967). A significant and positive correlation between photosynthesis and relative growth rate is indicating the fact that assimilation of CO_2 and its fixation is directly related to the growth rate which finally contributed to the overall productivity of these varieties (Vandana and Bhatt 1996). The process of transpiration is important in controlling the leaf temperature was prominent in all varieties. The rate of transpiration was maximum in summer when the atmospheric and PAR was highest as was reported by Haseba *et al.* (1967) and Bhatt (1990). The decrease in the rate of transpiration in winter months may be due to aging of leaves and decrease in temperature and PAR. The lowest rate of water losses during the process of transpiration in S24 exhibits its economical water use for sustainability of growth in hot summer. The significant correlation of transpiration with atmospheric temperature PN and stomatal conductance indicates their interrelationships (Table 4.1.16 and Fig. 4.1.25).

Table 4.1.16: Correlation coefficient between PN and other growth parameters in *Leucaena leucocephala* varieties.

Characters	VARIETY				
	S24	S22	S14	S10	K8
Dry weight	- 0.6767	- 0.5933	- 0.5861	- 0.7532	- 0.7786
Plant height	- 0.5780	- 0.4845	- 0.4742	- 0.7804	- 0.6584
Leaf area	- 0.4714	- 0.5757	- 0.4732	- 0.5361	- 0.6181
TR	0.7342	0.3835	0.3808	0.0145	0.3211
PN vs CS	0.4805	0.3372	0.2372	0.1909	0.6494
PAR	- 0.4440	0.0460	0.3353	- 0.1052	- 0.1821
AT Max.	- 0.2930	0.0102	- 0.1392	- 0.3992	- 0.1732
AT Min.	- 0.2552	- 0.0120	- 0.1761	- 0.1591	- 0.0707
RGR	0.4131	0.4439	0.1424	0.4765	0.6039

The uptake of CO_2 by plants in the process of photosynthesis is directly related to the stomatal conductance (CS) (Fig. 4.1.26). Similar to the CO_2

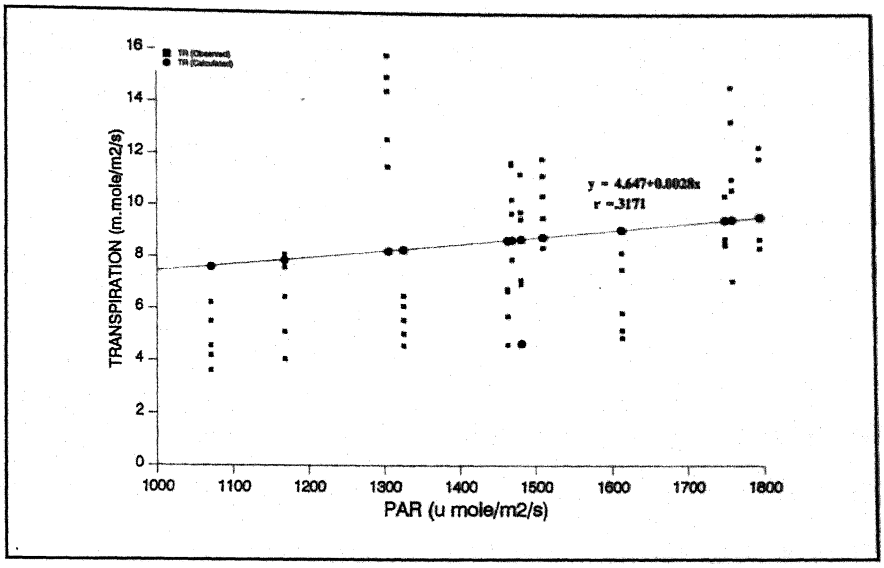


Fig. 4.1.25 : Relationship between photosynthetically active radiation and transpiration in *Leucaena leucocephala* varieties.

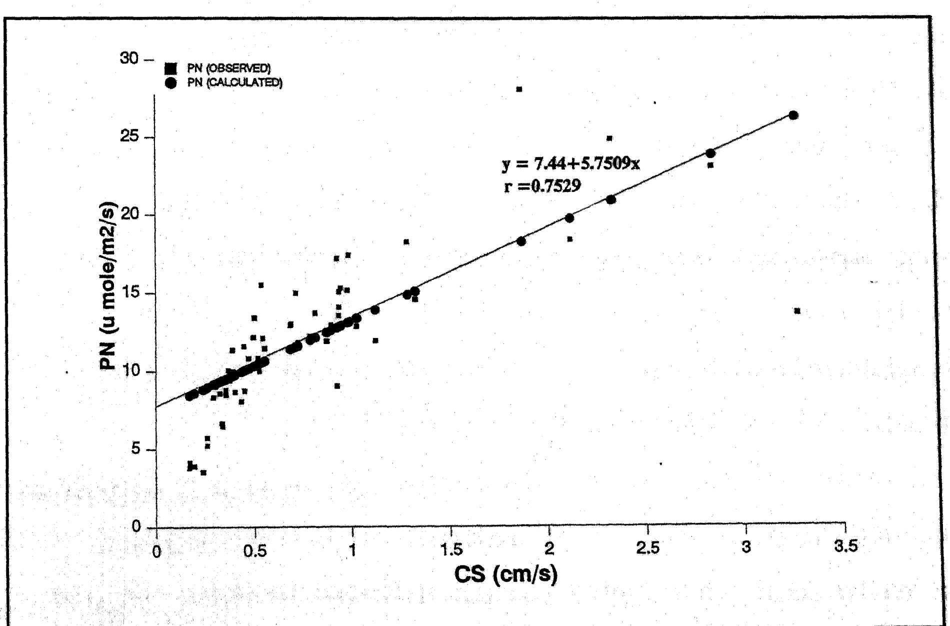


Fig. 4.1.26 : Relationship between photosynthesis and stomatal conductance in *Leucaena leucocephala* varieties.

assimilation rate, stomatal conductance was maximum in rainy season and minimum in summer months in all the varieties. However, S24 maintained the relatively high stomatal conductance for efficient CO_2 assimilation. The stomatal conductance was found to decrease with increasing atmospheric temperature as also reported by Heath and Orchard (1957) and Lange *et al.* (1969). It is found to be positively correlated with PN, TR and RGR (Table 4.1.16). Intercellular CO_2 concentration has not shown any definite trend with respect to seasons and varieties. However, intercellular CO_2 concentration was low in peak growing months predicting its fast fixation during the course of photosynthesis. The water use efficiency (a ratio of PN/TR). Which is intimately associated with the loss of water from the leaves to the atmosphere was found to be lowest in summer months may be due to high loss of water vapour through transpiration. The highest water use efficiency in December predicated their optimum growth during this period. S24 and K8 maintained higher water use efficiency indicating their superiority over other varieties.

The carboxylation efficiency (a ratio of PN and CINT, Farquhar and Sharkey 1982) was highest in rainy season and lowest in summer in all the varieties. The maximum carboxylation efficiency of S24 indicates its higher productivity potentiality over the other varieties and may be selected as fast and high producing variety for semi arid climates. PN/CINT is positively correlated with stomatal conductance (CS) and water use efficiency (PN/TR) indicating that these traits are important for selecting a plant variety for fast growth and biomass production. Photosynthetic rate and PN/CINT ratio are positively correlated as was reported by Dejong *et al.* (1984). The total biomass production in terms of fresh weight and dry weight after one year of growth was maximum in variety K8 and minimum in S14 and other varieties were almost equal in their biomass productivity (Table 4.1.13). The maximum biomass accumulation in K8 may have occurred due to the higher biomass of branches. One of the interesting point which emerges from this study that variety S24 produced maximum biomass during rainy season which indicates its faster growth.

However, the decrease in biomass accumulation in the later growth stage may be due to one or other reasons. Dry matter production was found to be

positively and significantly correlated with plant height, stem diameter, leaf number, leaf area and root length revealing the simultaneous growth of all the parts (Table 4.1.15. The strong and positive correlation of dry matter with leaf area indicates the dependence of biomass productivity and the assimilatory surface area (Fig. 4.1.27). Maximum dry matter production was observed between October to January. Relative growth rate (RGR) in terms of dry matter accumulation per unit of dry matter showed peakrecurrent growth flushes between July to November. Which may be due to the rise in CO_2 assimilation in rainy season accompanied by high stomatal conductance, and the optimum air temperature PAR and relative humidity as was reported by Vandana (1996) and Singh *et al.* (1982).

However the relative higher RGR in S24, S10 and K8 showed their optimum growth in extreme summer temperature. RGR was found to be positively correlated with the photosynthetic rate, transpiration, carboxylation efficiency and the water use efficiency indicating there by the dependence of growth flushes on these parameters (Table 4.1.16). Maximum amount of dry matter partitioning was seen in the stem than roots and leaves in almost all the varieties except S14 in which maximum biomass partitioned to roots. These findings are similar to those of Singh and Yadava (1991), Lodhiyal *et al.* (1992) and Rana *et al.* (1989).

At the early seedling stage the partitioning of biomass was found in leaves but with the growth of plants, partitioning of biomass was distributed to shoot for branch growth. Root / Shoot ratio was found to be higher as the plant matured which is usually in summer months when the air temperature was above optimal and moisture deficits prevailed as was reported by Fernandez and Caldwell (1975) and Jorden and Nobel (1984). Maximum amount of root: shoot ratio was reported in variety K8 in the month of April predicting its more biomass allocation to root growth. During dormant growth phase in winter months, maximum partitioning was observed in roots which is related with the findings of Sah *et al.* (1994). The high root: shoot ratio in winter months indicates the fact that root and shoot growth did not synchronize in *Leucaena leucocephala* varieties.

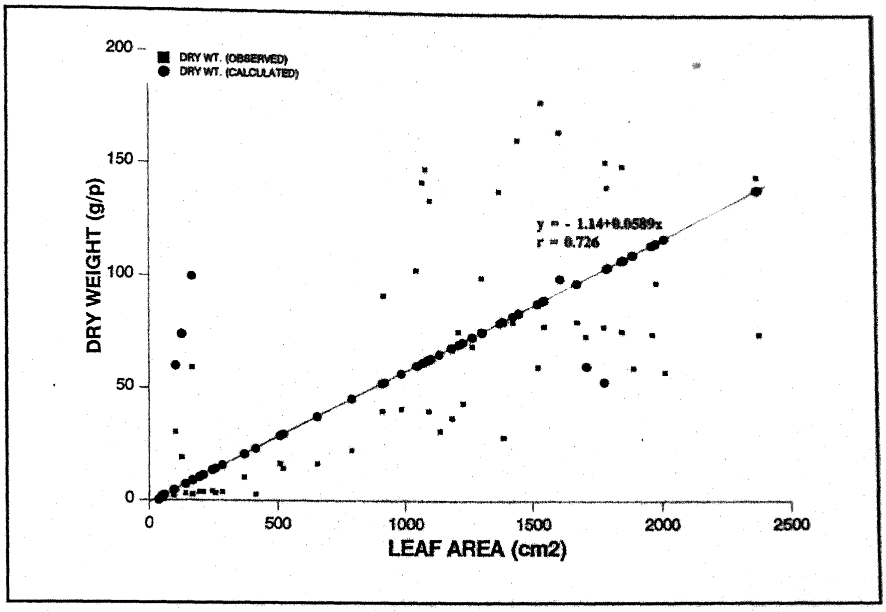


Fig. 4.1.27 : Relationship between leaf area and dry weight in *Leucaena leucocephala* varieties

It also shows that root / shoot ratio decreased as the soil temperature decreased and wetter conditions increased as was reported by Davidson(1969) and Radin and Bazlevich (1967). At low temperature photosynthates diverted to roots resulting in high root / shoot ratio (Beever and Cooper 1964).

Leaf area expansion growth was found to be closely related to the seasons. It is found to increase continuously as the seedlings grow but falls steeply as the leaves fall or senescence occurs in winter and again increases as the leaf flushing takes place during May-June. The leaf area was found to be maximum in S14 and minimum in K8 whereas other varieties were at par. Leaf area is positively correlated with all morphological characters and indicates its contribution to overall productivity of plant (Table 4.1.17 a,b,c,d,e). As the temperature increased the leaf area was also found to increase and these results were related to the findings to Kozlowski and Clausen (1966).

Table 4.1.17 a: Correlation matrix for different growth parameters in different varieties of *Leucaena leucocephala (S24).*

Parameters	Height	Diameter	Root length	Branches	Leaves	Dry weight	Leaf area
Height	1.0000						
Diameter	.97470	1.00000					
Root length	.96520	.92542	1.00000				
Branches	.70815	.76775	.75145	1.00000			
Leaves	.81143	.74339	.83008	.71345	1.0000		
Dry weight	.91361	.92838	.84033	.60711	.63419	1.00000	
Leaf area	.82295	.83112	.85456	.91324	.89907	.70947	1.0000
SLW	.64063	.50865	.66645	.27811	.69540	.47544	.5252
RGR	-.8832	-.85379	-.96110	-.80557	-.8361	-.74162	-.8916
REG	-.8506	-.78011	-.90020	-.54540	-.7833	-.65321	-.7041
R:S	.53089	.47002	.64851	.58195	.54823	.24641	.5946

	SLW	RGR	REG	R:S
SLW	1.00000			
RGR	-.56106	1.00000		
REG	-.60729	.89231	1.00000	
R:S	.39972	-.68706	-.59099	1.00000

Critical value (1-Tail,.05) = + or - .49932
Critical value (2-tail, .05) = + or - .57400
N = 12

Specific leaf weight which represents the average leaf dry weight per unit leaf area is found to increase as the growth of seedlings takes place but is found to be related more to the seasonal changes than to the age of leaf as also reported by Ledig *et al.* (1974). All the selections were higher in SLW than K8 exhibiting their superiority for higher productivity. SLW was found to be maximum in the month of December when the temperature was low (Peet *et al.* 1977) or otherwise when leaves attained full growth.

The specific leaf area is considered to be a measure of the environmental influence on the leaf area expansion (Evans 1972). Although no definite trend was observed among varieties but according to season it was significant. Leaf weight ratio gives an idea of the total dry matter allocated to the leaves than other plant parts.

Table 4.1.17 b: Correlation matrix for different growth parameters in different varieties of *Leucaena leucocephala (S22)*.

Parameters	Height	Diameter	Root length	Leaves	Dry weight	Leaf area	SLW
Height	1.0000						
Diameter	.99120	1.00000					
Root length	.98502	.97896	1.00000				
Leaves	.90198	.91235	.85290	1.00000			
Dry weight	.90334	.89372	.88923	.83346	1.0000		
Leaf area	.90915	.92620	.89845	.86347	.88778	1.00000	
SLW	.27573	.29884	.26220	.42646	.25458	.15722	1.0000
RGR	-.9388	-.94835	-.96903	-.76598	-.8028	-.88165	-.2389
REG	-.8289	-.82467	-.78958	-.74859	-.5858	-.78895	-.0138
R:S	.35099	.37201	.39499	.32826	.01822	.21202	.4512
Branch	.80796	.83142	.83891	.60114	.64490	.80234	-.0127

	RGR	REG	Branch	R:S
RGR	1.0000			
REG	.79589	1.0000		
Branch	-.88518	-.81725	1.0000	
R:S	-.49597	-.37299	.31439	1.0000

Critical value (1-Tail,.05) = + or - .49932
Critical value (2-tail, .05) = + or - .57400
N = 12

At seedling stage it was very low and decreased with leaf growth but when leaves attain maturity it again decreased due to more partioning of biomass to other plant parts. On an average all the selections of *Leucaena leucocephala* were having maximum LWR indicating their higher foliage production potentiality. The leaf area ratio is an index of leafiness and also an expression of the ratio of assimilatory or photosynthetic and non-photosynthetic products.

At seedling stage the LAR was highest may be due to high assimilatory surface area which then decreased as the respiratory mass increased. However, no significant difference was observed among the varieties with respect to their leaf area ratio. All the varieties of *Leucaena leucocephala* accumulated more photosynthetic pigments (chl, a, chl b, chl a+b and chl a:b) at their maximum in rainy season during early seedling growth and again increased from April to June.

Table 4.1.17 c: Correlation matrix for different growth parameters in different varieties of *Leucaena leucocephala* (S14).

Parameters	Height	Diameter	Root length	Leaves	Dry weight	Leaf area	SLW
Height	1.0000						
Diameter	.94941	1.0000					
Root length	.97275	.97567	1.0000				
Leaves	.91047	.91153	.90013	1.0000			
Dry weight	.88869	.96087	.92316	.85850	1.0000		
Leaf area	.72888	.62177	.64118	.66439	.51763	1.0000	
SLW	.60739	.59612	.63596	.67916	.61613	.07578	1.0000
RGR	-.9098	-.85382	-.88297	-.86491	-.7599	-.82170	-.5557
REG	-.9237	-.83407	-.87490	-.80821	-.6920	-.77980	-.4987
R:S	.90767	.88767	.92991	.67620	.81714	.66166	.6462
Branch	.73619	.78755	.72207	.89210	.67960	.70727	.2091

	RGR	REG	Branch	R:S
RGR	1.0000			
REG	.92707	1.0000		
Branch	-.77766	-.74452	1.0000	
R:S	-.87027	-.82282	.72490	1.0000

Critical value (1-Tail,.05) = + or - .49932
Critical value (2-tail, .05) = + or - .57400
N = 12

The increase in chlorophyll content in June may have occurred due to the flushing of new leaves (Kakati and Yadava, 1990 and Naidu and Swamy, 1996). The accumulation of chlorophyll content decreased in autumn and winter seasons with the mature leaves. Maximum synthesis of chlorophyll contents was estimated in S24, S22, S14 and S10 than K8 exhibiting their higher photosynthetic efficiency. The chl a:b indicates the photosynthetic efficiency of plants which decreased with the increase of SLW (Bhatt and Sinha 1990). Maximum carotene content was estimated in S10 and lowest in S22. Nitrate reductase activity in leaves increased with the growth of leaves and reached at higher level at the full mature stage of leaf which then subsequently decreased. Similar trend was also reported by Muthuchelian *et al.* (1986). In summer months the NRA activity decreased due to higher temperature in these months.

Table 4.1.17 d: Correlation matrix for different growth parameters in different varieties of *Leucaena leucocephala* (S10).

Parameters	Height	Diameter	Root length	Branches	Leaves	Total dry weight	leaf area
Height	1.0000						
Diameter	.98608	1.00000					
Root length	.97650	.96924	1.00000				
Branches	.87052	.89628	.85437	1.00000			
Laeves	.93928	.95654	.92298	.84234	1.0000		
Dry weight	.91818	.92080	.86125	.78654	.82649	1.00000	
Leaf area	.80370	.77438	.85762	.72130	.68514	.67920	1.0000
SLW	.43027	.41821	.45864	.28182	.51654	.38895	.1104
RGR	-.8852	-.86686	-.93199	-.83786	-.8106	-.77991	-.9304
REG	-.8574	-.80780	-.80685	-.63486	-.8288	-.70561	-.7233
R:S	.55861	.51939	.62987	.64978	.54389	.27668	.7191

	SLW	RGR	REG	R:S
SLW	1.00000			
RGR	-.33193	1.00000		
REG	-.32229	.70920	1.00000	
R:S	.13280	-.74993	-.51519	1.00000

Critical value (1-Tail,.05) = + or - .49932
Critical value (2-tail, .05) = + or - .57400
N = 12

It was also reported by Hauffakar *et al.* (1970), Kauffaman *et al.* (1971). In the *Leucaena leucocephala* varieties the NRA activity was estimated upto 1237.27 m u mole NO_2/g F W./hr. in S14.

The sugar content was found to increase with the age of plant as was reported by Vandana (1996) in *Sesbania* species. Season wise variations were found to be significant in leaf, stem and roots sugar content while variety wise variations were significant in only root. So there was a pronounced effect of season on the sugar accumulation. Variety S10 accumulated high sugar content in leaves and roots whereas variety S24 accumulated in roots.

The starch content was also found to increase with the age of plant parts. The starch content was low in winter months when the rate of photosynthesis was low. Similar findings were reported by Potter (1980) and Naidu and Swami (1996). All the varieties were found to be significant with respect to season and variety.

The higher accumulation of carbohydrate (sugar and starch) in roots in variety S24 exhibits its higher regeneration potential because the stored carbohydrate may be used for the regeneration of coppice and its growth.

Table 4.1.17 e: Correlation matrix for different growth parameters in different varieties of *Leucaena leucocephala* (K8).

Parameters	Height	Diameter	Root length	Branches	Leaves	Total dry weight	leaf area
Height	1.0000						
Diameter	.96822	1.00000					
Root length	.59629	.50887	1.00000				
Branches	.71376	.69950	.14829	1.00000			
Laeves	.87224	.88892	.48316	.59721	1.0000		
Dry weight	.83105	.92401	.36729	.52067	.78973	1.00000	
Leaf area	.87586	.84200	.47668	.86520	.84706	.65829	1.0000
SLW	.74710	.75715	.60020	.29997	.74487	.67695	.5220
RGR	-.9413	-.88458	-.49256	-.86301	-.8005	-.69522	-.9354
REG	-.8425	-.76841	-.52760	-.63523	-.7058	-.60308	-.7579
R:S	.57473	.45691	.44889	.70649	.58125	.17544	.8066

	SLW	RGR	REG	R:S
SLW	1.00000			
RGR	-.64256	1.00000		
REG	-.59042	.80742	1.00000	
R:S	.25201	-.71679	-.48294	1.00000

Critical value (1-Tail,.05) = + or - .49932
Critical value (2-tail, .05) = + or - .57400
N = 12

In the early stage of growth the leaves were found to be rich in crude protein . Similar trend was reported by Majumdar *et al.* (1967). The protein content was maximum in rainy season (Gupta *et al.* 1992) which is found to be positively related to leafiness (Paroda 1975). As the tree grows in size there was a pronounced increase in the crude protein content (Mendoza *et al.* 1983). Leaves and roots have maximum accumulation of crude protein than that of stem.

Chapter 4.2

Growth and Production of Plantation on DEGRADED LAND

4.2

Growth and Production of Plantation on Degraded land

4.2.1 Varietal Characteristics

The morphological features viz., length of the 3rd leaf, number of pinna per leaf, length of pinna, number of pinnule pairs, weight of leaf, number of flowers per head, length of pod, maximum breadth of pod, number of locules, number of seeds/pod, weight of seeds and weight of empty pods were studied to characterize the varieties (Plate 5). These features are as under:

Leaf characters

Leaf length : Maximum leaf length was recorded in S10 (14.5 cm) followed by S22 and K8 which was equal in leaf length and minimum was in variety S14 (10.8 cm) (Table 4.2.1).

Number of pinna / leaf : The maximum number of pinna were observed in variety S10 (17.8) and the minimum was in S24 (12.8) while S22, S14 and K8 were at par.

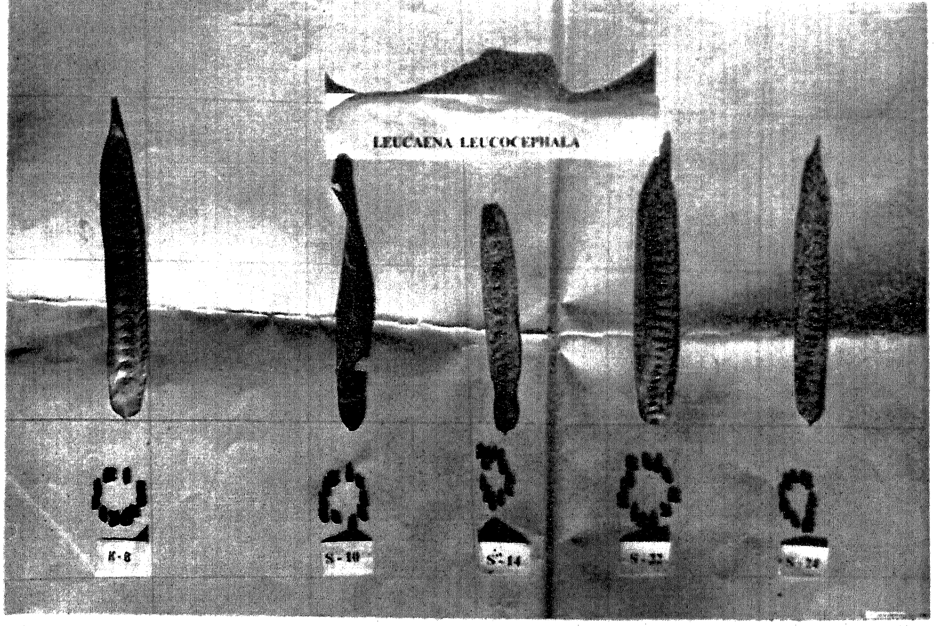
Length of pinna : Variety S10 recorded maximum pinna length (7.8 cm) and the minimum was in S14 (5.3 cm) while the varieties K8 and S24 had the pinnae of same size.

Number of pinnule pairs : The maximum number of pinnule pairs were observed in the variety S10 (17.8) and the minimum in variety S14 (13.6).

Flower characters

The maximum number of flowers per head were maximum in K8 (103.3) and the minimum in variety S22 (94.9) (Table 4.2.1).

A



B

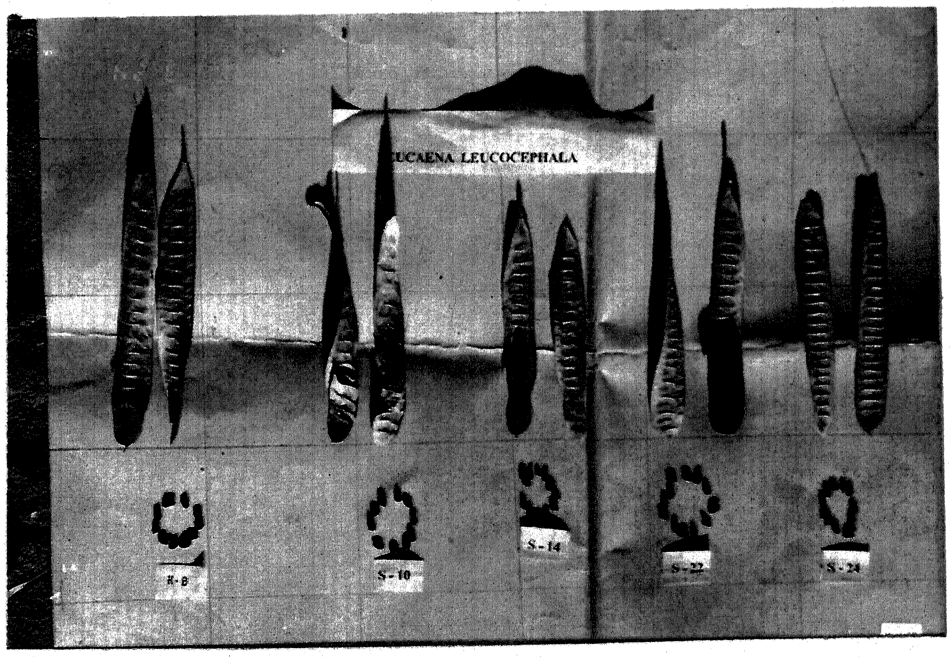


Plate 4 : Pods and seeds of different varieties of *Leucaena leucocephala*.

A) Closed pods

B) Open pods

Table 4.2.1 : Morphological attributes (Leaf, flower and mimosine %) of *L.leucocephala* varieties.

Characters	VARIETY				
	S24	S22	S14	S10	K8
Leaf Characters					
Length (cm)	12.9	14.2	10.8	14.5	14.2
No. of pinna/leaf	12.8	14.4	14.8	17.8	14.4
Length of pinna (cm)	6.6	6.1	5.3	7.8	6.6
No. of pinna pairs	16.4	15.4	13.6	17.8	15.8
Flower Characters					
No. of flowers/head	116.6	94.9	119.9	103.0	130.3
Mimosine (%)	2.9	3.74	3.77	2.92	3.28

Pod characters

The pods have been studied in two seasons i.e., in winter (February) and summer (June) (Table 4.2.2).

Pod length : In winter maximum pod length was observed in variety K8 (20.0 cm) and the minimum in variety S24 (14.6 cm) whereas in summer the maximum pod length was recorded in variety S10 (19.94 cm). Variety S24 continued to produce smaller pods.

Pod breadth : The maximum pod breadth during winter was found in variety S22 (2.38 cm) while the minimum was in variety S10 (2.0 cm). Varieties S14 and S24 have shown the same breadth (2.18 cm) in winters. In summer, maximum breadth of pod has been recorded in variety S22 (2.19 cm) followed by S10 and the minimum in variety S24 (1.48 cm) while other varieties produced pods of equal breadth.

Number of locules per pod : In winter maximum number of locules were observed in variety S10 (21.3) while the minimum was in variety S14 (17.4). In summer maximum number of locules / pod were found in variety S14 (23.8) and the minimum in variety S24 (18.6).

Number of seeds / pod : Variety S10 produced maximum number of seeds per pod (20.30), whereas S14 produced the minimum (17.2) during winter season. In summer the maximum number of seeds / pod were observed in variety S14 (22.4) while the minimum was in variety K8 (17.5) (Table 4.2.2).

Weight of seeds per pod : Maximum seed weight was observed in variety S10 and minimum in variety K8 in winter season and these varieties also maintained similar trend in summer season.

Seed test weight : maximum seed test weight i.e, 1000 seeds weight was recorded

Table 4.2.2 :Pod characters of *L. leucocephala* during the two seasons

Pod characters	Season	VARIETY					Mean	CD
		S24	S22	S14	S10	K8		
Pod length (cm)	Winter	14.6	16.21	16.75	18.85	20.0	17.3	1.838
	Summer	13.5	17.1	19.3	19.94	17.35	17.48	1.3
Pod breadth (cm)	Winter	2.17	2.38	2.18	2.0	2.38	2.2	0.118
	Summer	1.48	2.19	1.99	2.05	1.9	1.93	0.128
No. of locules/pod	Winter	18.9	17.8	19.0	22.1	20.5	19.66	2.896
	Summer	18.6	21.0	23.8	20.9	19.2	20.9	3.04
No. of seeds/pod	Winter	17.8	16.4	17.2	20.3	18.9	18.12	2.915
	Summer	17.9	19.1	22.4	20.7	17.8	19.58	3.05
Weight of seeds/pod	Winter	0.964	1.082	1.008	1.15	0.946	1.03	NA
	Summer	0.542	1.00	0.883	1.028	0.866	0.864	NA
Weight of pod	Winter	0.90	1.048	0.966	0.992	1.01	0.983	NA
	Summer	0.723	0.941	0.789	0.829	0.855	0.827	NA
Test wt. (g / 1000 seeds)	Winter	5.51	6.501	5.895	5.689	5.086	5.737	NA
	Summer	4.158	5.014	3.971	5.223	5.032	4.679	0.60
Seed / pod ratio	Winter	1.07	1.032	1.043	1.159	0.937	1.048	NA
	Summer	0.749	1.062	1.119	1.24	1.013	1.045	NA

NA = Not available

in S22 and S10 in winter and summer seasons respectively. On an average all the varieties produced higher seed test weight in winter than seeds produced during

summer.

Seed / pod ratio : Seed / pod ratio was observed maximum in S10 in winter and summer season and minimum in K8 and S24 in in summer and winter respectively.

Mimosine : Mimosine accumulation in leaves was estimated during the month of December at the full leaf growth. The mimosine percentage ranged from 2.9 - 3.77% and maximum percentage of mimosine was estimated in variety S14 (3.77%) and S22 (3.74%) while the minimum was in variety S24 (2.90%) and S10 (2.92%).

4.2.2 Growth of Varieties in the Field Plantation

In earlier studies, Gupta (1989-91) and Pathak and Gupta (1994) studied the growth and production of 15 different varieties of *L. leucocephala* in the field trials. Since the same plantation has been used for coppice growth and production study, selections S24, S22, S14, S10 and K8 were selected for the initial growth and data are presented in table 4.2.3.

The mean collar diameter growth was 12.24 cm. On an average the varieties gave more collar diameter growth than K8. The peak growth was in S10 (13.3 cm) followed by S24 (13.1 cm) while S14, S22 and K8 were at par in their collar diameter growth (Table 4.2.3). The varietal differences were statistically significant.

The diameter growth at breast height (dbh) showed its peak (10.1 cm) in S10 and the minimum in S22 (8.9 cm). The varieties again gave more dbh growth than that of K8 except S22 after five years of plantation growth. There was significant variation between the varieties.

The height growth although was statistically significant, but recorded to be same in varieties S24, K8, S14 and S10. variety S22 attained lower growth as compared to other varieties.

4.2.3 Seasonal Coppice Growth

The growth attributes (collar diameter, breast height diameter, plant height, number of branches, clean bole height and canopy cover) of regenerating plantations after the first cycle felling were studied in every season at the gap of three months

Table 4.2.3 : Growth of *L.leucocephala* varieties.

Variety	Collar diameter (cm)				dbh (cm)	Height (m)			
Age (Months)	6*	18*	30*	60**	60	6	18	30	60
S24	1.2	4.8	9.2	13.1	9.5	0.96	5.8	8.6	12.8
S22	1.3	4.6	8.3	11.4	8.9	1.2	5.4	7.9	11.7
S14	1.3	5.2	8.6	11.8	9.9	1.2	5.6	7.9	12.5
S10	1.2	5.1	9.2	13.3	10.1	1.2	5.7	8.7	12.5
K8	1.3	5.4	8.9	11.6	9.1	1.1	5.8	8.1	12.8
Mean	1.3	5.0	8.8	12.2	9.5	1.1	5.7	8.2	12.4
Cd at 5%	-	-	-	1.3	1.1	-	-	-	0.97

* based on Gupta (1989-1991), **based on Pathak and Gupta (1994), - not available.

from March 95 to March 96 (Fig. 4.2.1, 4.2.2 and Plate 3a & b)). The results are as under:

Mean collar diameter growth

At the end of two years (March 1996), coppice growth of *Leucaena leucocephala* varieties showed maximum mean collar diameter growth in variety S22 (9.6cm) and minimum in variety S10 (8.4cm). It has been observed that maximum growth in terms of collar diameter took place during rainy season between the months of June and September. In all the seasons variety S22 was leading in collar diameter growth while S10 had the minimum growth at March 1996 observation. Earlier to this S14 recorded the minimum diameter. It shows a shift in growth rate with the time in varieties. (Fig 4.2.1a).

Mean breast height diameter growth

At the end of two years of coppice growth variety S 22 had maximum growth (7.7cm) in terms of dbh while variety S 24 and K 8 were found in equal growth (7.5cm). In all the varieties maximum dbh growth occurred in rainy season during the months of June to september. Among the selected varieties, variety S 22 showed maximum growth in dbh in all the months of growing season (Fig 4.2.1b plate 4).

A

B

Plate 5 : *Leucaena leucocephala* coppice growth at one year (April 1995).
A) A general view
B) A close-up view

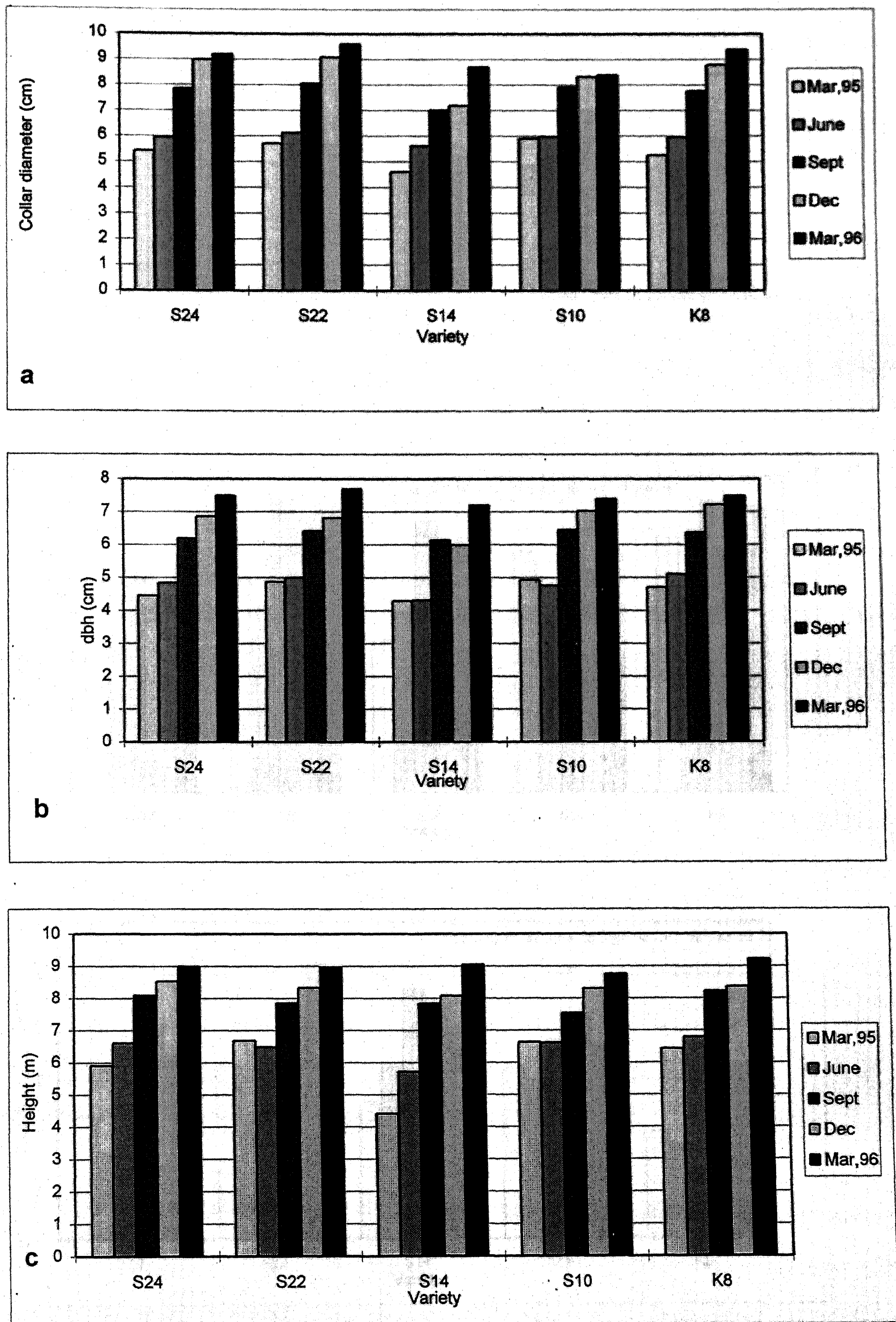


Fig. 4.2.1 : Coppice growth of *Leucaena leucocephala* during different seasons
(a= collar diameter, b= dbh, c= Plant height)

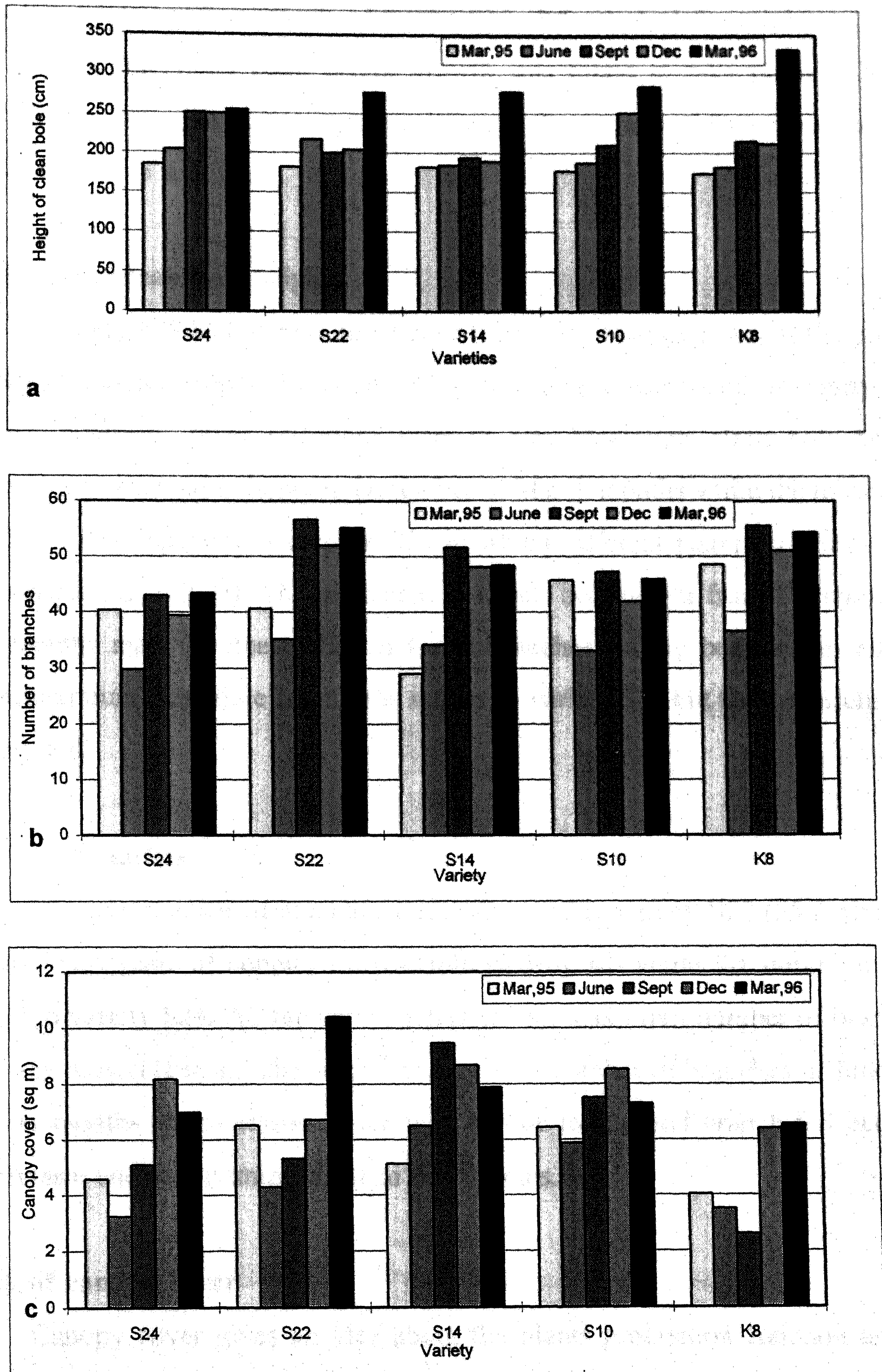


Fig. 4.2.2 : Coppice growth of *Leucaena leucocephala* during different seasons
(a= Height of clean bole, b= Number of branches, c= Canopy cover)

Tree height growth

Variety K8 attained maximum growth in terms of plant height (9.2 m) at the end of two years coppice growth while the S10 (8.8 m) had the minimum plant height growth. Maximum plant height growth was found to take place in rainy season and the minimum during summer between the months of December to June (Fig 4.2.1c, plate 5 a & b).

Growth of the clean bole height

The variety K 8 had maximum height of the clean bole (3.32 m) at the end of two years of coppice growth. Minimum clean bole height was found in variety S24 (2.55 m). Whereas other selections were at par. Maximum clean bole height increment was observed in between December to March months while the minimum during March to September except in S24 in which different pattern of clean bole was recorded (Fig. 4.2.2a). The increment in clean bole height from December to March months may be due to fall of lower branches. In the begining in all the seasons maximum clean bole height was shown by variety S24 but the minimum was in variety K8.

Number of branches

Maximum number of branches were observed in variety S22 (55.1/plant) at the end of two years of coppice growth followed by K8 while the minimum was observed in variety S24. All the varieties had shown maximum number of branches in the rainy season (Fig 4.2.2b). There was a fall in number of branches in June and December months of the season which may be due to leaf and branch fall because of senescence and self pruning habit in this species.

Growth of canopy cover

Canopy cover gives an idea about the plants production function and its interactions. After two years of coppice growth variety S22 was with maximum canopy cover growth (10.4 sqm) and variety K8 had the minimum (6.56 sqm). All the varieties responded positively in the rainy season with increase in canopy cover growth and showed decline in growth during the summer season from March to June

(Fig 4.2.2c).

4.2.4 Annual Coppice Growth

Collar diameter growth (CD)

In the first year of growth maximum collar diameter growth was attained by variety S10 (5.33cm) followed by S22, S24, K8 and S14. In the second year K8 showed maximum collar diameter (9.98 cm) followed by S22, S10, S14 and S 24 while in the third year S24 was maximum (11.96cm) followed by K8 and S10 (Table 4.2.4). The collar diameter growth across the varieties was found to be non significant during the years (Table 4.2.5).

Table 4.2.4 : Annual growth of coppice shoots in *Leucaena leucocephala* plantation.

Characters	Ist Year Growth			IInd Year Growth			IIIrd Year Growth		
Variety	CD (cm)	dbh (cm)	Height (m)	CD (cm)	dbh (cm)	Height (m)	CD (cm)	dbh (cm)	Height (m)
S24	5.28	3.55	6.38	8.25	7.03	9.50	11.96	9.50	10.59
S22	5.30	3.80	6.84	9.05	7.53	9.20	10.69	8.70	10.03
S14	4.88	3.48	5.94	8.43	6.88	8.82	9.25	7.70	9.30
S10	5.33	3.59	6.54	9.03	7.13	9.01	10.54	8.60	10.00
K8	5.13	3.83	6.24	9.98	8.40	9.41	11.26	9.07	10.29
Mean	5.18	3.65	6.38	8.95	7.39	9.19	10.74	8.71	10.04
CD at 5%	NS	NS	0.47	NS	0.96	NS	-	-	-

NS = Non significant, - = Not available

Table 4.2.5: Analysis of variance of coppice growth in *L. leucocephala* varieties during the second year of coppice growth.

Characteristics	Value of CD		
	Variety	Season	Interaction
Colar diameter	1.208**	1.351***	NS
dbh	NS	1.154**	NS
Plant height	49.15***	54.95***	25.57***
Height of cleanbole	NS	40.99***	18.33***
No. of branches	6.80***	7.61***	3.41***
Canopy cover	2.32**	2.60**	NS

** Significant at 1% level, *** Significant at 0.1% level, NS = Non significant

The current annual increment in collar diameter in the second and third year of

growth was found to be less than that of mean annual increment (Table 4.2.6).

Breast height diameter (DBH)

The variety K8 was leading in the first year of growth (3.83 cm) followed by S22 where as other varieties were equal in their dbh growth. The same trend was observed in the second year of growth while in the third year the variety S24 was leading (9.5 cm) followed by K8, S10, S22 and S14. The variation in dbh growth of varieties was significant in only the second year of annual growth.

The breast height diameter increment also followed the same trend as of the collar diameter increment with mean annual increment more than the current annual increment (Table 4.2.6).

Table 4.2.6 : Current and mean annual coppice growth increment in *L. leucocephala*

Annual Increment	Attribute	Age (Year)	VARIETY S24	S22	S14	S10	K8	Mean
Current	CD	1	5.28	5.3	4.88	5.33	5.13	5.18
		2	2.98	3.75	3.56	3.71	4.86	3.77
		3	3.71	1.64	0.82	1.51	1.28	1.79
	dbh	1	3.55	3.8	3.48	3.59	3.83	3.65
		2	3.48	3.73	3.40	3.54	4.57	3.74
		3	2.47	1.17	0.82	1.47	0.67	1.32
	Height	1	6.38	6.84	5.94	6.54	6.24	6.39
		2	3.12	2.36	2.86	2.47	3.17	2.8
		3	1.09	0.83	0.48	0.99	0.88	0.85
Mean	CD	1	5.28	5.3	4.88	5.33	5.13	5.18
		2	4.13	4.53	4.21	4.52	4.99	4.48
		3	3.99	3.56	3.08	3.51	3.75	3.58
	dbh	1	3.55	3.8	3.48	3.59	3.83	3.65
		2	3.52	3.77	3.44	3.57	4.2	3.7
		3	3.17	2.9	2.60	2.90	3.02	2.92
	Height	1	6.38	6.84	5.94	6.54	6.24	6.39
		2	4.75	4.6	4.41	4.51	4.71	4.6
		3	3.53	3.34	3.10	3.33	3.43	3.35

Height growth

In the first year of growth the maximum height in variety S22 was (6.84m) followed by S10, S24, K8 and minimum is S14. In the second year variety S24 and K8 recorded maximum height growth followed by S22 and S10 . In the third year growth same pattern of height growth was observed as in the second year. The height growth variation between the varieties was significant in only the first year of annual growth.

The height growth increment also followed the same pattern with higher mean annual increment compared to the current annual increment (Table 4.2.6)

4.2.5 Phenology

The phenological events were observed on the field plantations as well as in the pot culture . All the five selected varieties have been studied right from their germination.

In pot culture study healthy and scarified seeds were sown by the end of May in polythene bags. The seeds started germinating after second day of sowing. Maximum number of sprouts were found in variety K8 and the minimum in variety S10 and S22. After 15 days of the sowing maximum percentage of germination was observed in variety K8 (78.67 %) and the minimum was in variety S10 (55.33%).

The seed germination in nature starts after first few showers in June and July and the young seedlings begin to appear subsequently and continue upto September when the mean temperature ranged between 25-35^0 C. Appearance of seedlings in August and September is mostly due to staggered germination of seeds as they are deep burried at the deeper soil layers.

In the pot culture studies seedlings were transplanted from the polythene bags to pots in the first week of July. The growth of young plants is slightly faster in the rainy season (July to early October) and in spring (late February to April) when the temperature ranges from 20 - 31 ^{0}C.

Early seedling growth up to October was found to be maximum in variety K8 and the minimum in S10. By the April overall vegetative growth was maximum in variety S24 which with the advent of winter season, showed suppressed vegetative growth in all the varieties due to sudden fall in temperature. Similarly as the

summer starts perticularly by mid May the vegetative growth becomes slow upto some extent. It is due to hot winds and sudden rise in temperature. With the onset of monsoon season they further resume their vegetative growth.

The leaf litter fall in these varieties is through out the year with maximum in summer (April to June) followed by winter (November to February). Leaf fall peaks are associated with changes in temperature, humidity as well as anthesis and pod maturation. The maximum leaf fall was found in variety S14 and the minimum in K8.

Flowering also ocurs in all the varieties in two phases. The first phase was found to start by the end of September which lasts for about two months and shows a gradual decline with the advent of winter season. The second phase of flowering occurred in March- April. The flowers of winter months were found to be larger in size and brighter in colour than of the summer season. Variety K 8 was first to start flowering and the varieties S22 and S24 were the late in flowering.

The pollination occurred soon after the buds open which is mainly by air and after that the fruit formation starts. The winter pods ripe by February while the summer pods ripe by mid May. The winter pods were larger in size with heavier and dark coloured seeds as compared to the summer pods with light weight and coloured seeds. The pods also had more weight in winter as compared to summer ones (Table 4.2.2).

In the field plantations the area was dry with low level of soil moisture (being rainfed). It exhibited early flowering and fruit maturity while pot culture experiments were responding to only the climatic changes. These modifications in the phenological events therefore are the response to environmental conditions such as climate, soil, temperature and soil moisture levels.

To understand the behaviour of each variety for leaf retention and fall, monthly leaf / stem ratio was determined.

4.2.6 Leaf / Stem Ratio

The changing leaf / stem ratio in the twigs at the apical parts of the canopy (branches with less than 0.5 cm diameter) during different months was measured in each variety by collecting five twigs randomly from all the three replications. To

assure that the branches are of a diameter between 0.3 - 0.5 cm and from a uniform height from the ground in the canopy, sampling was carefully done. the twigs were kept in paper bags, brought to laboratory, leaves were separated from the stem and after recording their weight were kept in hot air oven for recording their dry weight. On the same date, the soil was also sampled at two levels of 0 - 15 and 15 - 30 cm depth. The soil samples were also used for estimating the soil moisture. The computed data were used for comparing the varieties for their leafiness. The monthly behaviour of the varieties was as under:

S 24

The stem (branch / twigs) dry matter remained more than 50% during January, February and June with its peak during January while it was minimum in August (36.39%) (Fig. 4.2.3). Leaf dry matter was maximum during June (55%) and minimum during August (26.89%). During three months April, May and June the leaf dry matter was more than 50% and remained more than the stem dry matter where as in the other months stem dry matter was more than the leaf. The maximum variation in dry matter of leaf and stem was in month of July (27.4 and 48.4%), respectively while in the month of December it was minimum and leaf and stem had almost equal dry matter (44 and 45%). The shape of the curve also indicates the periods of maturity and new leaf initiation. Leaf / stem ratio on the dry and fresh weight basis do not show much variation but on dry weight basis the ratio was lower than the fresh weight basis during rainy season. The soil moisture remained more than 10% during July and August after which it declined. It is apparant from the curves that with the changing soil moisture, the leaf and stem dry matter also changed. (Fig 4.2.3)

S 22

Perusal of figure indicates that the stem remained more than 50% during January, February, March and June with its peak during January (63%) while it was the minimum in August (35.95%). Leaf dry matter was maximum during January (54.1%) while the minimum was in August (23.31%). In the month of December and January the leaf dry matter was more than 50%. During the month of December,

April and May the leaf dry matter was found to be more than that of stem dry matter. It was December when leaf and stem had almost similar dry matter (49 and 51%). Leaf / stem ratio on dry and fresh weight basis do not show much variation but on dry weight basis the ratio was lesser than the fresh weight basis during rainy season. The other parameters remained similar to the variety S24 (Fig 4.2.4).

S 14

Like varieties S 24 and S 22 this variety has also shown maximum stem dry matter during the months of January and February. It was recorded maximum in the month of February (63%) and minimum in August (30.36%). During the months of January and May the leaf dry matter was more than 50%. The leaf dry matter remained more than the stem dry matter during the months of December, April and May, while in other months stem dry matter was more than the leaf. The maximum variation in dry matter of leaf and stem was in the month of February (37.7- 63.6%) while the minimum was in December (44 - 47%). All other parameters were similar to the other two varieties (Fig. 4.2.5).

S 10

The variety had shown more than 50% dry matter in stem during the months of July, January and February. Maximum stem dry matter was observed in July (57.84%) which was found to be highest among all the varieties. The minimum dry matter was observed in the month of September (31.2%). The leaf dry matter had shown its peak during the month of February (60.6%) while the minimum was observed in August (25.03%). During the month of January, February and May the leaf dry matter was found to be more than 50%. This variety had shown more leaf dry matter than the stem dry matter in the months February, March and May. Maximum variation in dry matter percentage was observed in the month of July (32 - 57.8%) while minimum in the month of March at 46.9 and 47.8%. All other parameters were found to be similar to the previous varieties (Fig. 4.2.6).

K 8

In the months of January, February and April the stem dry matter was found

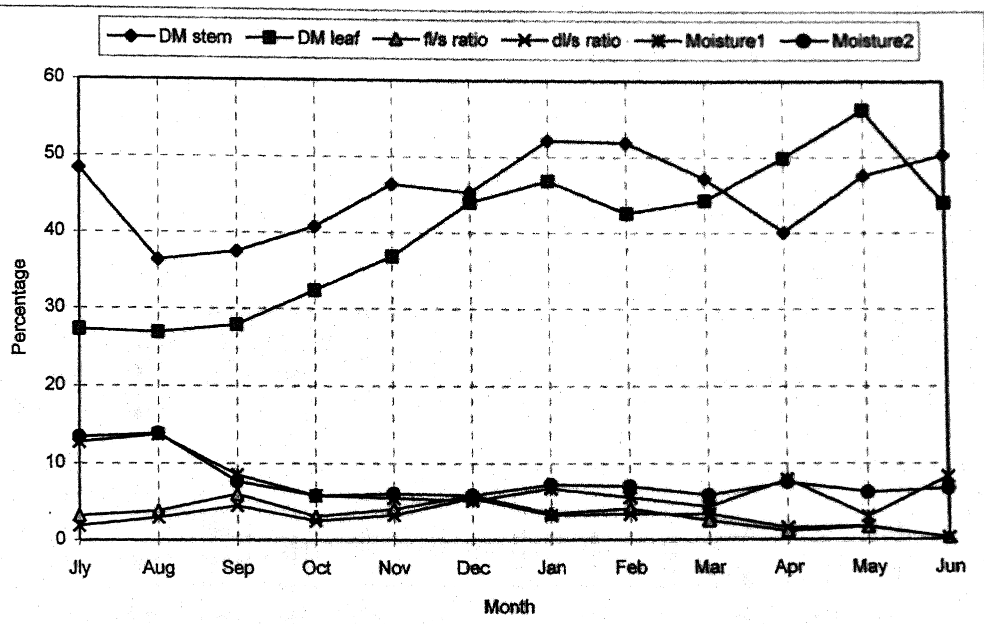


Fig. 4.2.3 : Dry matter and leaf / stem ratio in *L. leucocephala* (var S24)

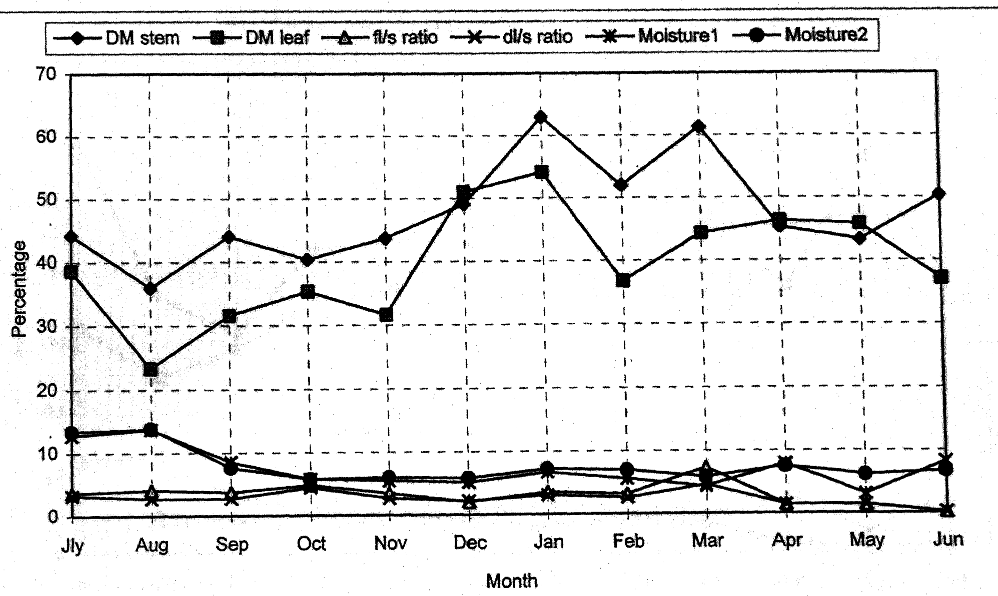


Fig. 4.2.4 : Dry matter and leaf / stem ratio in *L. leucocephala* (var. S22)

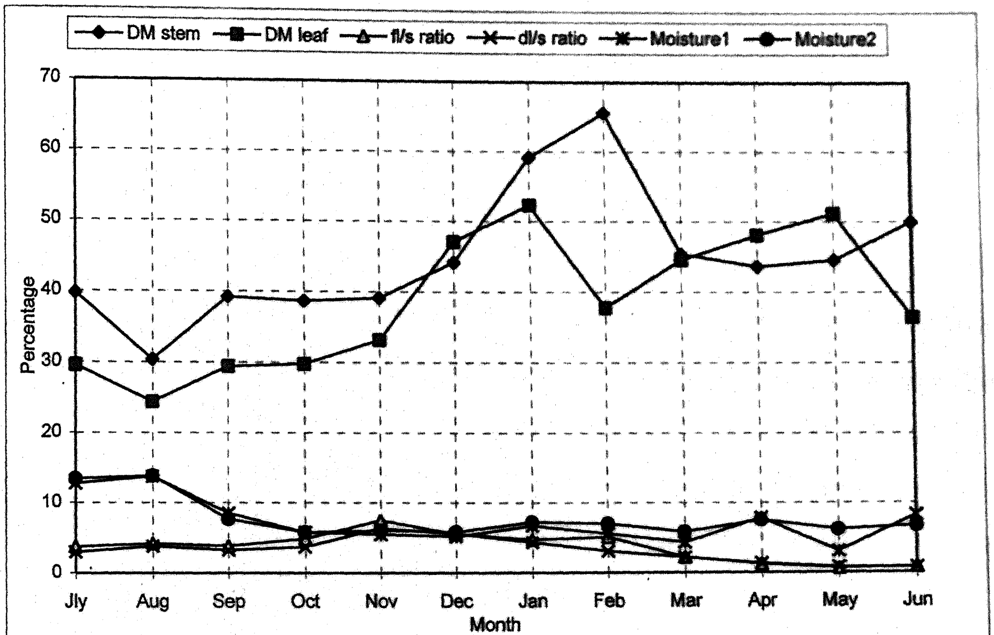


Fig. 4.2.5 : Dry matter and leaf / stem ratio in *L. leucocephala* (var. S14)

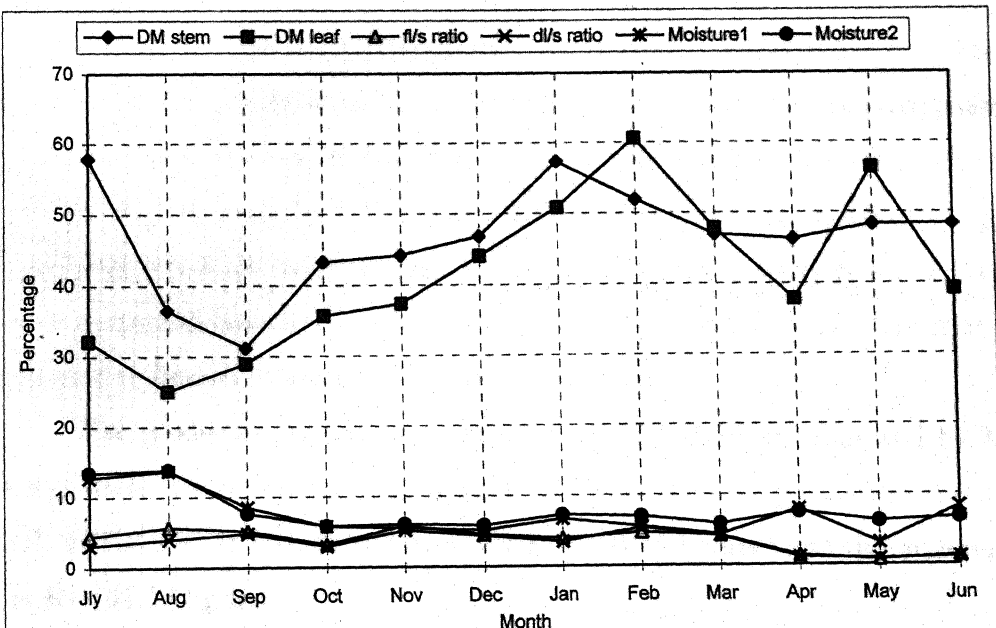


Fig. 4.2.6 : Dry matter and leaf / stem ratio in *L. leucocephala* (var. S10)

to be more than 50% (Fig 4.2.7). It was recorded maximum in the month of January (56.6%) and minimum in August (35.54%). Leaf dry matter was observed maximum in the month of March (52.6%) while the minimum was in June (24.8%). During the month of January, February and March the leaf dry matter was observed at or more than 50%. In the month of February leaf and stem dry matter were almost same while maximum variation between them was observed in June (between 24.8 - 43%). All other parameters were found to show similar trend (Fig. 4.2.7)..

Over all comparison of all the five varieties, shows the minimum variation for leaf / stem ratio during April and the maximum during November and December. During winters maximum leaf / stem ratio was observed in S14 while the minimum was in S22 (Fig. 4.2.8) . During April to June the leaf / stem ratio remained less than 2 in all the varieties while it was more than 5 in S14, K8 and S10 during November, in S14 during December and S10 in February. During July and August in all the varieties leaf / stem ratio was between 2-4.

4.2.7 Biomass Production

Five year growth

Pathak and Gupta (1994) reported only above ground production at five years. Biomass (oven dry weight) production was measured separately for the components of bole, branch and leaf in each tree (Table 4.2.7). Peak bole biomass was produced in S24 (39.2 kg) followed by S10 (36 kg) while the minimum was in K8 (26.4 kg). The selections produced more biomass as compared to K8. Variety S10 (12.7 kg) produced maximum branches followed by S24 . The difference between the varieties with respect to branch production were non significant.

The production of leaf was maximum in S24 (5.36 kg) followed by K8 (3.24 kg) while the minimum was in S14 (1.38 kg). The total production showed its peak in S24 (56.36 kg/tree) followed by S10 (50.16 kg/tree) and the minimum was in K8 (41.34 kg/tree).

One year coppice growth

During the first year as a measure of the stand management, at 5 months after the clear felling, the coppice shoots were allowed thinning. Only one leading shoot

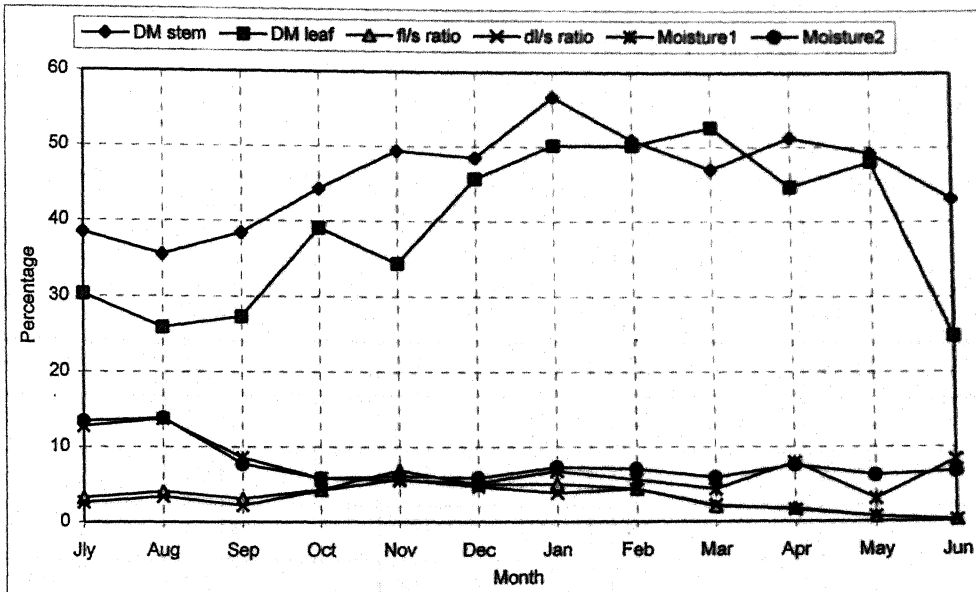


Fig. 4.2.7 : Dry matter and leaf / stem ratio in *L. leucocephala* (var. K8) during different months

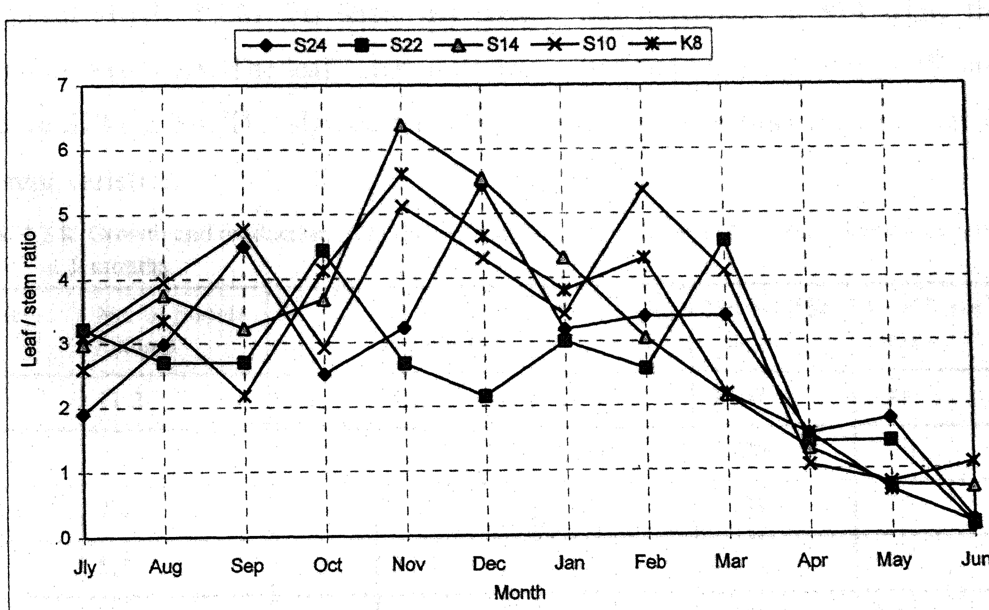


Fig. 4.2.8 : Leaf / stem ratio in *L. leucocephala* varieties during different months

was left per stump and those removed were counted, height was noted and weighed. Samples were kept for dry weight recording. It was observed that maximum number of shoots were produced in S24 and the minimum in S14. Maximum height was produced in S22 (3.65 m) while the minimum was in S14 (3.12 m). S22 produced

Table 4.2.7: Biomass production (kg/tree) of *L. leucocephala* varieties at five years (after Pathak and Gupta 1994).

Variety	Bole	Branch	Leaf	Total
S24	39.2	11.8	5.36	56.36
S22	30.8	10.9	3.03	44.73
S14	34.3	7.5	1.38	43.18
S10	36.0	12.7	1.46	50.16
K8	26.4	11.7	3.24	41.34
Mean	33.34	10.92	2.89	47.15
CD at 5%	7.3	NS	1.41	-

maximum total fresh weight (4.515 kg) and K8 produced the minimum (3.138 kg). Out of these three parameters recorded, only height growth was statistically significant (Table 4.2.8). Per shoot dry weight was maximum in S14 while the minimum was in K8. The leaf / stem ratio was calculated higher in S10 (3.95) and lower in S22 (2.70). This showed the allocation pattern even from the early age in different varieties.

Table 4.2.8: Growth and production from the thinning of coppice shoots of *L. leucocephala* varieties at 5 months.

Variety	No. of Shoots / stump	Height (m)	Fresh weight (kg)	Dry weight (kg)	Dry weight / shoot	Leaf /stem ratio
S24	11.2	3.5	4.077	1.198	0.107	3.84
S22	9.5	3.65	4.515	1.224	0.129	2.70
S14	7.4	3.12	3.954	1.024	0.139	3.75
S10	8.1	3.55	3.331	0.93	0.122	3.95
K8	8.9	3.55	3.138	0.904	0.102	3.35
Mean	9	3.48	3.803	1.057	0.117	3.05
CD	NS	-	NS	-	-	-

At one year after the harvest the biomass production was measured seperately

for the above ground components (bole, branch and leaf) and below ground parts (stump and roots) (Plate 6).

Above ground biomass production : S10 produced highest bole biomass (4.89 kg) followed by S22, K8, S24 and lowest bole biomass production was recorded in S14. The variation in biomass production of varieties was found to be significant statistically (Table 4.2.9). Branch production was maximum in variety S22 (1.65 kg) followed by S10, K8, S24 and S14. The variation between the varieties was non significant statistically.

Leaf production was recorded in the month of March and it has been observed that S10 produced maximum leaf biomass per tree (0.99 kg) followed by S14, K8, S22 and S24. The variation between the varieties for leaf production was found to be significant statistically. The above ground production was maximum in variety S10 followed by S22 and K8 while S24 and S14 were at par in their above ground biomass production potential.

Below ground biomass production : Stump + root production was found to be highest in variety S22 (3.72 kg) followed by S10, K8 and lower in S14 and least in S24. The below ground production was also significant between the varieties (Table 4.2.9).

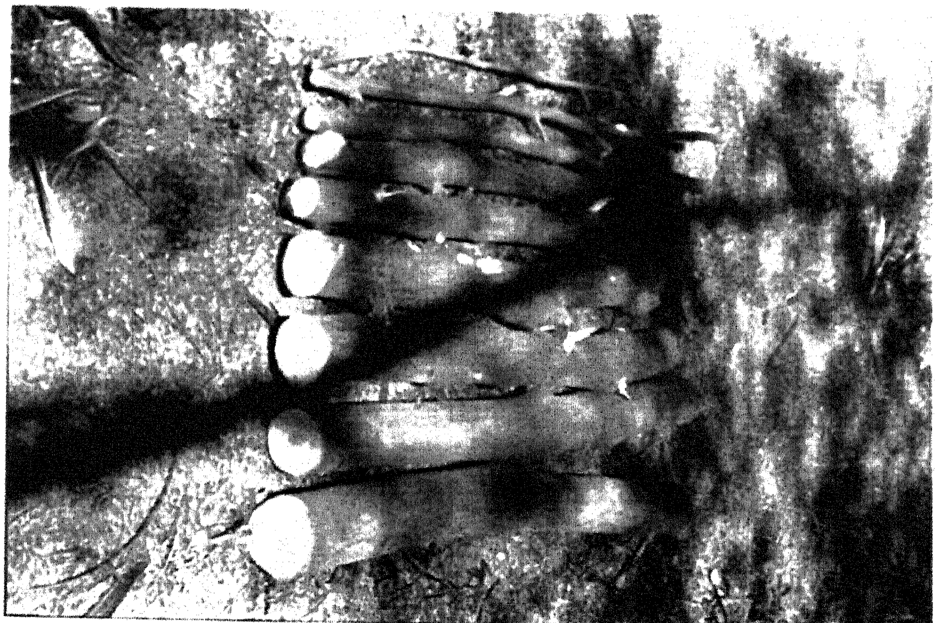
The total (above ground + below ground) biomass production was at its peak value in S22 (10.14 kg) followed by S10 (9.95 kg) and the minimum was in S24 (6.11 kg).

Two year coppice growth

The second year of coppice growth along with above ground and below ground production were estimated during March 1995. The annual litter fall collected in different months was also added to the total biomass production for all the varieties.

Above ground biomass production : The highest bole biomass production was in S24 (16.96 kg) followed by K8, S22, S10 and S14. The variation in production between

A



B

Plate 6 : A) Bole segments of 2 year old coppice growth of *Leucaena leucocephala* (March 1996).

B) A close-up view of the bole surface.

the varieties was found to be significant statistically.

Table 4.2.9 : Biomass production (kg / tree) of first year coppice growth in *L. leucocephala* varieties

Variety	Bole	Branch	Leaf	Yield of coppice thinning	Total above ground	Stump+ below ground	Total
S24	3.131	0.605	0.436	1.198	5.370	1.935	7.305
S22	4.198	1.647	0.578	1.224	7.647	3.720	11.367
S14	2.713	0.522	0.787	1.028	5.050	2.535	7.588
S10	4.893	1.237	0.985	0.930	8.050	2.833	10.878
K8	3.808	0.696	0.598	0.904	6.006	2.723	8.729
Mean	3.748	0.941	0.665	1.057	6.407	2.749	9.160
CD	1.22	NS	0.381	-	-	0.997	-

The branch production was maximum in S22 (4.15 kg) and minimum is S10. The varietal variations were analysed statistically non significant (Table 4.2.10)

The leaf biomass production was maximum in S22 (1.67 kg) whereas other varieties were at par in the leaf production. The varietal variations were non significant statistically. The total above ground production was maximum in S24 (21.6 kg) followed by S22, K8, S10 and S14. The variety S14 and S10 gave lower biomass than the mean.

Below ground biomass production : The maximum below ground biomass production was recorded in S22 (15.35 kg) followed by K8, and S14. The varieties S24 and S10 were equal in their below ground biomass production potential. The varietal variations were found to be statistically significant. (Table 4.2.10).

Litter production : The litter production at the end of second year of coppice growth was found to be maximum in K8 (3.5 kg/tree) followed by S14, whereas S22, S24 and S10 produced almost equal amount of litter. Considering the leaf biomass at the end of 2 years, K8 produced minimum leaf biomass / tree and the maximum litter.

Litter production and dry matter allocation : The monthly litter production in all the varieties showed that all followed similar trend (Fig. 4.2.9) . It showed three peaks

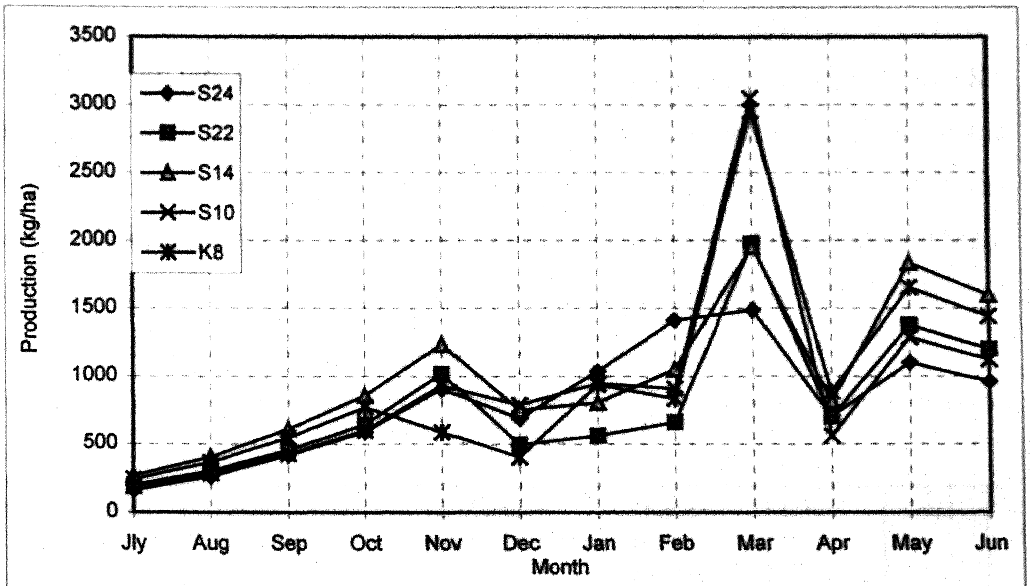


Fig. 4.2.9 : Litter production in the *L. leucocephala* plantations during different months

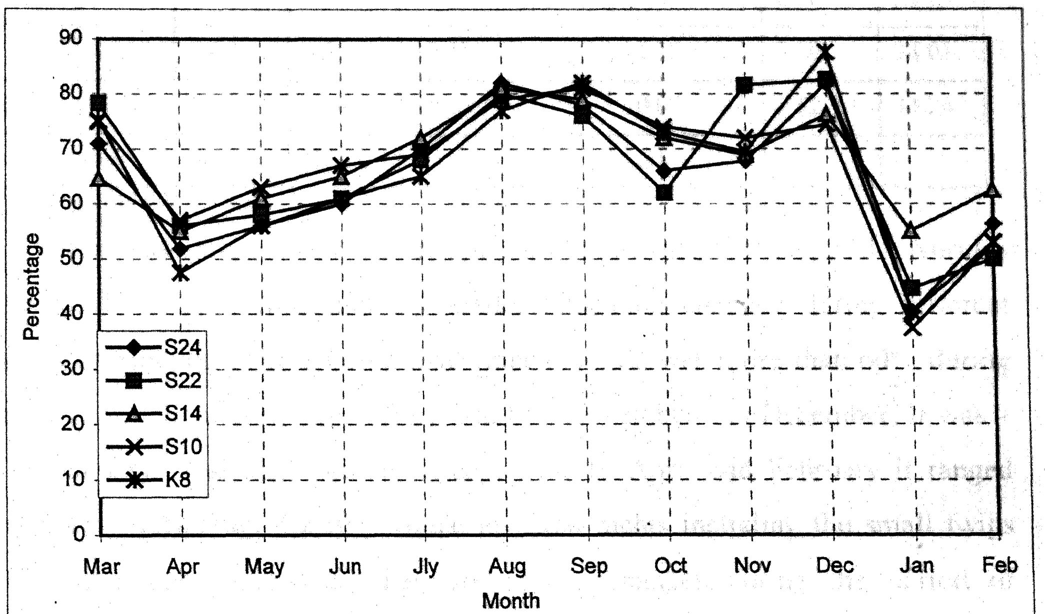


Fig. 4.2. 10 : Contribution of leaf (%) in the litter of *L. leucocephala* during different months

of litter production during (November, March and May). The minimum production was observed in July in S24 (160 kg/ha) and the maximum was in S10 and K8 (about 3000 kg/ha) in the month of March, produced equal amount of litter in the months of July, August, September, October, December and April . In all the varieties maximum variation in the litter production was observed in March and May. Over all maximum litter production was obtained in the month of March followed by May and November and the minimum was in July.

Table 4.2.10 : Biomass production (kg / tree) of coppice growth of *L. leucocephala* varieties in second year .

Varieties	Bole	Branch	Leaf	Total above ground biomass	Stump+ below ground	Litter	Total
S24	16.96	3.54	1.10	21.6	7.85	2.67	32.12
S22	13.55	4.15	1.67	19.66	15.35	2.79	37.50
S14	10.55	3.61	0.98	15.13	8.02	3.24	26.39
S10	13.18	1.83	1.002	16.01	7.80	2.38	26.19
K8	14.58	3.66	0.94	19.18	11.33	3.50	34.01
Mean	13.76	3.36	1.14	18.25	10.07	2.92	31.24
CD	3.0	NS	NS	-	3.36	-	-

NS = Non significant

Litter was composed of leaf, rachis including twigs, flowers, pod coverings and seeds. Their proportion and dry matter allocation changed during different months. Contribution of leaf in the total litter biomass was more than 60% during March, June, July, August, September, October, November and December. It was > 50% in January in all the varieties except S14. In April and February it ranged between 45 - 60% (Fig. 4.2.10). Since leaf and rachis including the small twigs formed the major component, their fortnightly changes during the period of production are presented in figure 4.2.11 and 4.2.12. A perusal of figures indicated that varietal variation in allocation was quite prominent during different months. During November, December and March more than 65% dry litter biomass was allocated to leaves while it was less than 50% in all the varieties except S14 in the month of January. During the remaining months, It was between 50 - 60%. Inter varietal variations were minimum in second fortnight of March in all the varieties.

(Figure 4.2.11)

Allocation to twigs was highly variable among the varieties during different months. Thus 40% and more twig biomass was observed during November and April in S10. It remained less than 35% in all the varieties during all the months. Only 5% allocation was observed in S24 and K8 during December first quarter when allocation to leaf was more than 90% in these varieties. Inter varietal variations were the minimum during second fortnight of April (Fig 4.2.12).

Three year coppice Growth

The biomass production of third year coppice growth was estimated on the basis of first and second year coppice growth through regression models developed for dbh and height growth (Table 4.2.11).

Above ground biomass production : At the end of third year variety S24 has shown maximum bole biomass (20.01 kg) followed by K8 and S10 whereas S22 and S14 were equal in bole biomass production. The production in S22 and S14 was found to be lesser than that of the varietal mean. The production of branch was also maximum in S24 (4.97 kg) followed by K8, S10, S22 and S14. The production of leaf had also shown the same trend with maximum in S24 and minimum in S14. The total aboveground production was maximum in S24 and minimum in S14.

Below ground production : S24 produced maximum below ground biomass (15.71 kg) followed by K8 and S10 whereas S22 and S14 were at par. At the end of third year variety S24 was leading in its total biomass production followed by K8.

The production of active fine roots and its mortality continues to be in continuous flux over the year. Its production is higher during the rainy season followed by February, March and lowest in May - June. Although it was not measured, but based on Rana *et al.* (1989), it was considered 20% of the leaf litter falling annually. Srivastava *et al.* (1986) consider one half or a greater fraction of the weight of the litter to be fine roots but the 20% part of the leaf litter was considered more accurate. In *Leucaena,* leaf litter constituted about 62% of the total

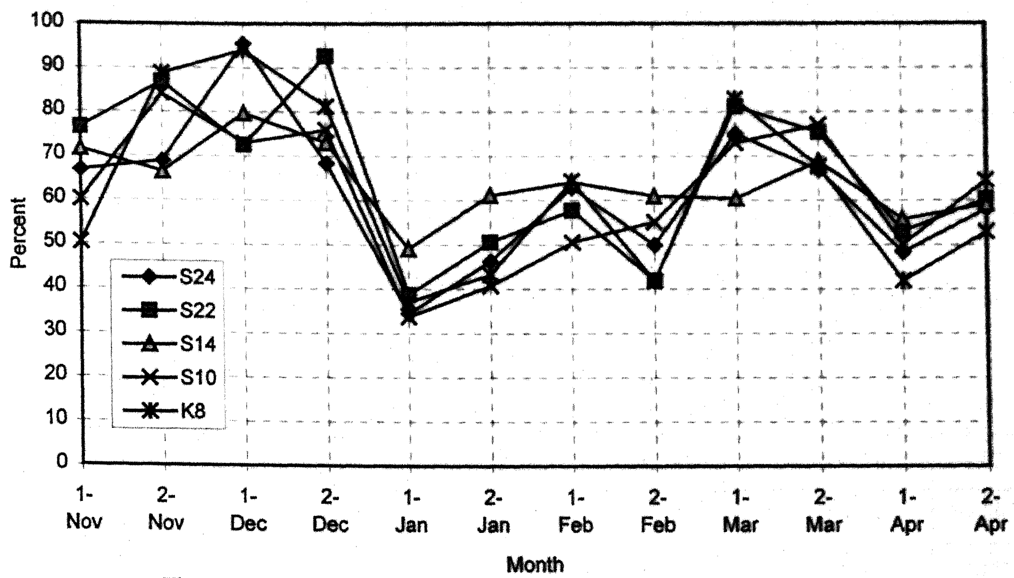


Fig. 4.2.11 : Dry matter allocation to leaf litter biomass by different varieties of *L. leucocephala*

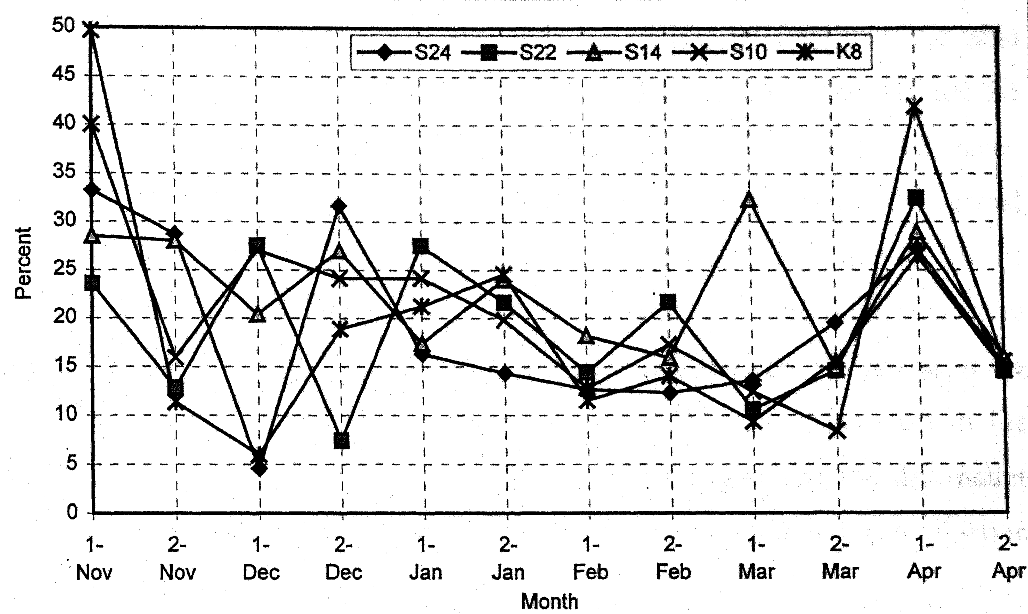


Fig. 4.2.12 : Dry matter allocation to twig litter biomass by different varieties of *L. leucocephala*

litter biomass. In *Anogeissus latifolia* forests on Vindhyans, Singh (1987) observed < 2 mm diameter component to be one third of the total biomass during the rainy season. Considering these and also the strong seasonality of growth with high litter fall during the dry months, 20% fraction was considered more appropriate.

Table 4.2.11: Biomass production (estimated kg/tree) of coppice growth in *L. leucocephala* varieties in the third year .

Variety	Bole	Branches	Leaf	Total AG	Stump+BG	Litter	Total
S24	20.81	4.97	1.43	27.21	15.71	3.80	46.72
S22	17.67	4.24	1.29	23.20	13.30	4.19	40.69
S14	14.12	3.41	1.14	18.67	10.57	4.78	34.02
S10	17.29	4.15	1.28	22.72	13.01	3.56	39.28
K8	19.09	4.57	1.36	25.02	14.39	4.48	43.89
Mean	17.80	4.27	1.30	23.36	13.40	4.16	40.92

4.2.8 Standing Crop of Biomass

Production of biomass per unit area in the first, second and third year of growth in different varieties is presented in table 4.2.12. It is apparent from the table that biomass production per unit area increased over the years. S24 and S10 are the higher biomass producers with 133.72 and 134.22 t/ha at the third year. The same varieties at 1 year showed 16.36 t more biomass in S10 over S24 and at the second year S24 gave 2.27 t more biomass. With the total biomass S22 remained the lowest with 85.88 t/ha at the end of third year. In the first year S10 produced the maximum (37.4 t/ha) while S24 being the lowest (21.04 t/ha), in second year K8 produced the maximum (96.28 t/ha) while S14 was the lowest (75.43 t/ha). This shift in the production over years is possible due to the growth strategies and the dry matter allocation pattern over the years.This is apparent from the woody biomass production (Table 4.2.12).

The wood biomass was maximum in S10 (21.89 t/ha) in first year and minimum in S24 (9.95 t/ha) and in second year of growth S24 produced the maximum (58.43 t/ha) and the minimum was in S14 (39.65 t/ha) whereas during the third year S24 remained maximum producer (73.47 t/ha). It clearly shows the varietal strategy for allocating more biomass to wood in S24 as compared to the others.

4.2.9 Production Ratios

In order to understand the dry matter allocation strategies of varieties, wood / bark, bole / branch and wood / leaf ratios were calculated (Table 4.2.13). The mean value of these parameters over time showed increase indicating flow towards bole wood.

Table 4.2.12: Standing crop of biomass (t/ha) at different age in *L. leucocephala* varieties at different age..

Variety	Age (yr)	Wood	Aboveground	Total
S24	1	11.75	15.30	21.04
	2	58.43	61.56	92.49
	3	73.47	77.55	133.72
S22	1	16.01	19.12	28.63
	2	44.25	48.40	94.69
	3	54.78	58.00	101.73
S14	1	9.95	14.14	21.62
	2	39.65	42.36	75.11
	3	49.08	52.28	96.00
S10	1	21.89	27.37	37.40
	2	51.03	54.43	90.22
	3	72.90	77.25	134.22
K8	1	13.55	16.82	24.79
	2	51.07	53.70	96.28
	3	66.25	70.06	123.57
Mean	1	14.55	18.39	26.70
	2	49.13	52.38	90.72
	3	63.30	67.03	117.85

The wood / bark ratio was maximum in S10 in year 1, K8 in year 2 and S22 and S24 in year 3. The minimum in year 1 was in S24, in year 2 in S14 and in year 3 in S14. This indicated the relative value of S24 for quality wood production.

The bole / branch ratio was maximum in K8 in year 1, S10 in year 2 and S24 in year 3. Minimum was in S22 in year 1, S14 in year 2 and S22 and S14 were at par in year 3. This clearly shows higher relative allocation to branch biomass with

age in S22 and S14. It is note worthy that *L. leucocephala* has a self pruning habit whereby, lower branches in a plantation are gradually shed.

The wood / leaf ratio shows the non photosynthetic biomass that can be supported per unit of the photosynthetic biomass. Maximum ratio in year 1 was in S24, year 2 in K8 and S24 in year 3. Similarly the minimum was in S14 in year 1, S22 in year 2, S14 in year 3. S24 and K8 did not follow any trend over the years while in rest of the thre, there was an increase with age.

Table 4.2.13 : Production ratios in the biomass of *L leucocephala* at different growth stages.

Variety	Wood/Bark ratio			Bole/Branch ratio			Wood/ Leaf ratio		
Age (Yrs)	1	2	3	1	2	3	1	2	3
S 24	5.13	11.0	13.16	5.19	4.79	4.19	8.57	18.63	18.03
S 22	7.57	12.85	12.03	2.55	3.27	4.14	10.11	10.61	15.61
S 14	7.03	8.01	11.95	5.20	2.93	4.14	4.11	14.48	15.38
S 10	7.93	12.0	12.61	3.96	7.21	4.17	6.22	14.98	16.75
K 8	7.14	15.4	12.93	5.47	3.99	4.18	7.53	19.51	17.40
Mean	6.96	11.6	12.54	3.98	4.10	4.16	7.05	15.07	16.75

Dry Matter Profile

During the harvest of above ground biomass, each tree was separated in to 1 meter segment from the base. In each segment the components of bole, branch and leaf were separated and weighed separately. Samples were drawn and kept in oven for determining the dry matter. The pieces of the bole were further separated in to wood and bark and weighed separately. The structure of the standing crop of biomass is given as under:

At 1 Year

Dry weight structure of bole : All the varieties had six segments except one tree in S22 having 7 and one tree each in S24 and S14 with 5 segments. In a pyramidal structure maximum biomass in the basal first segment was in S10 (2031.5 g)followed by S22 and K8. The minimum was in S24 (1109 g) (Fig. 4.2.13). The other segments followed the similar trend. On an average six segments were considered of which maximum dry matter partitioning was in basal parts of S14 (43.6%) followed by S10 and the minimum was in S22 (33.1%). The structure of dry matter in bole

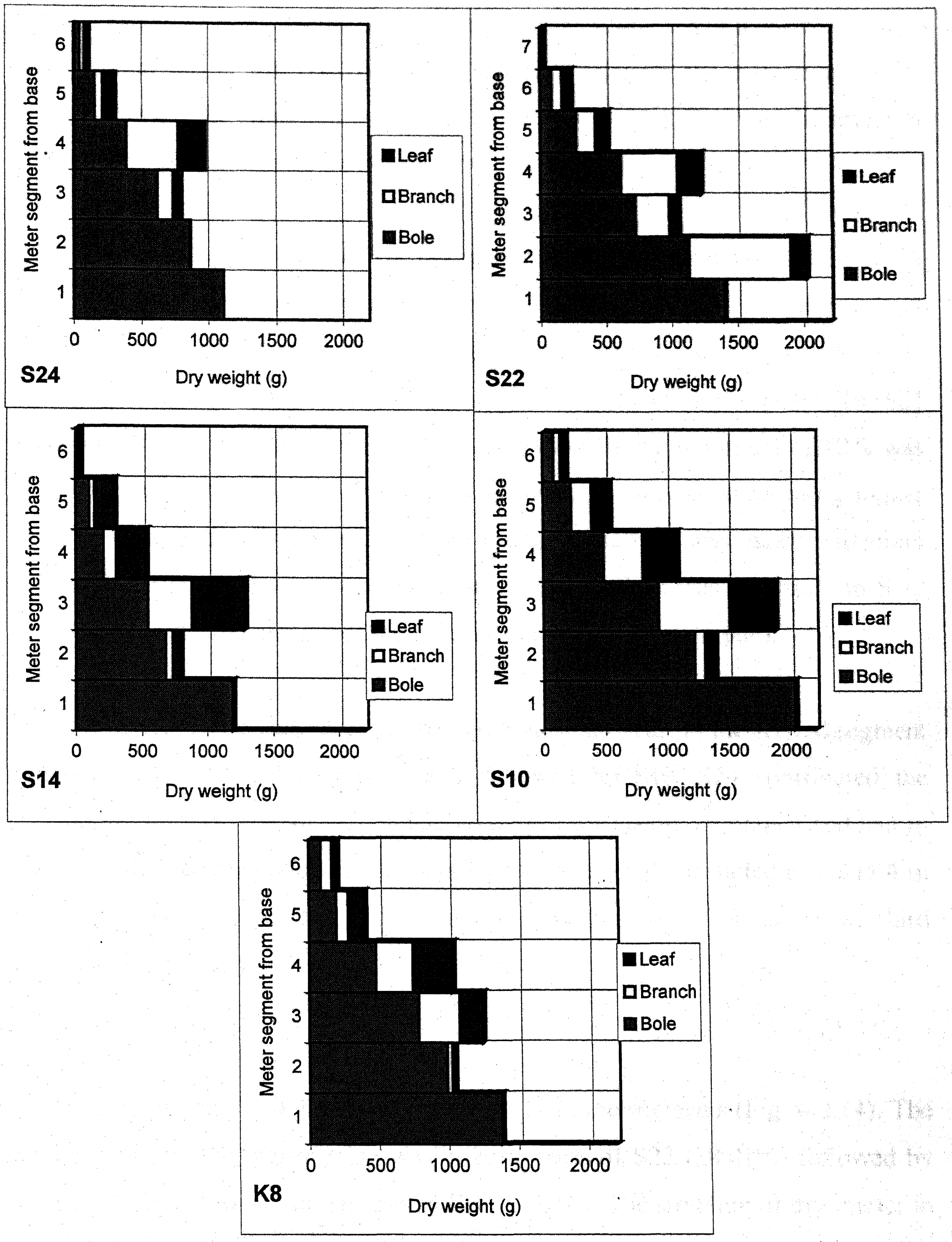


Fig. 4.2.13 : Dry matter profile in *L. leucocephala* plantation at Jhansi at one year of coppice growth (1995)

was in shape of pyramid. In the second segment, maximum was in S24 (27%) while the minimum was in S10 (24.5%). In the top most segment, the maximum was in K8 (2.2%) while the minimum was in S22 and S14 (0.003%). This was the situation when the bole biomass was measured above the stump level.

Dry matter percentage in wood : The dry matter in bole increased from 53.6 to 67% in S22 and K8 respectively at the age of one year. Such a high dry matter content in K8, S24 and S10 shows its specific trait. In K8 maximum dry matter of 69.4% was in the segment one while minimum of 60% was in segment six. In S22 maximum of 64% dry matter was in segment two while the minimum of 42% was in segment six. The dry matter in bark was lower to bole wood showing higher moisture compared to bole wood. The dry matter in the bark was again maximum in K8. The bole / bark ratio was maximum in S10 while it was minimum in S24. This indicates the relative allocation of each variety to different parts.

Branch and leaf: The basal segment had no branch and leaf. In the second segment maximum branch and leaf was in S22 followed by S10. S24 contributed the minimum. Third and the fourth segment accounted for maximum branch and leaf in almost all the varieties. Thus, the maximum canopy spread accounted at 3 and 4 m segments from the base. S14 contributed the maximum leaf biomass in the third segment (Fig. 4.2.13).

At 2 Year Age

Dry weight structure of bole : All the varieties had nine segments (Fig. 4.2.14). The maximum dry matter partitioning was in basal parts of S22 (28.01%) followed by S10 (27.42%) and the minimum was in K8 (22.78%). The structure of dry matter in bole was in the shape of a pyramid. In the second segment, maximum was in S14 (23.41%), while the minimum was in K8 (17.06%). In the top most segment the maximum was in S24 (3.5%) and the minimum in S14 (0.14%). This was the situation when the bole biomass was measured above stump level.

Dry Matter percentage in wood : The dry matter in bole rose from 56.18% to

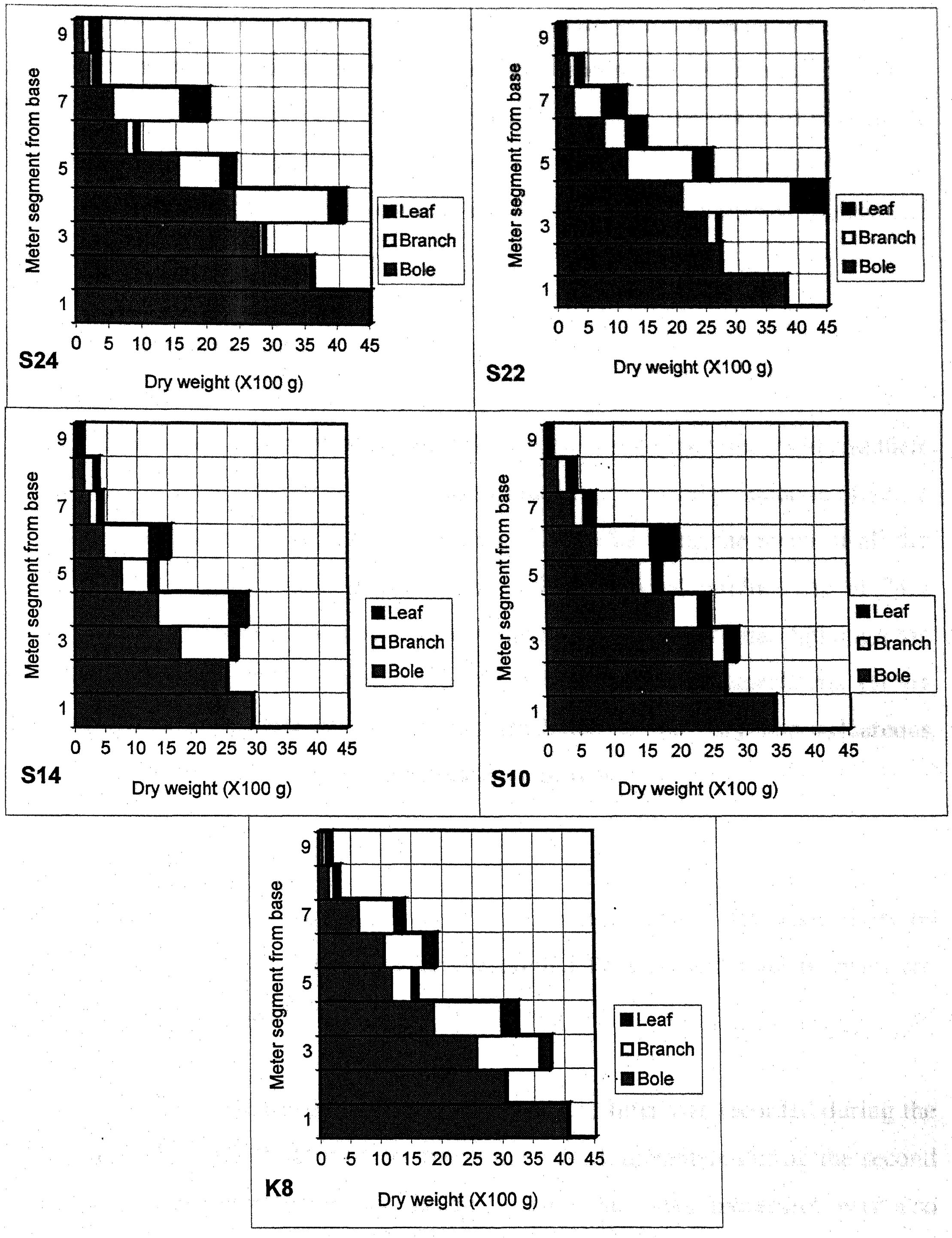


Fig. 4.2.14 : Dry matter profile in *L. leucocephala* plantation at Jhansi at two years of coppice growth (1996)

72.34% in S14 and S10 respectively at the age of two years. Maximum dry matter was in segment three and eight of S10 and S22 respectively. Minimum dry matter was in top segment of S14 (10%). The dry matter in bark was lower to bole in all the varieties showing higher moisture in bark compared to wood. The wood / bark ratio was maximum in the third segment of K8 and the minimum was in segment eight of S14.

4.2.10 Productivity

First Rotation

Pathak and Gupta (1994) reported that on the basis of per tree yield and their respective density, the calculated yield shows a maximum annual production of 32.12 t/ha by S24 compared to 23.1 t/ha by K8 and 21.74 t/ha being the mean of all the varieties. In the earlier study Pathak *et al.* (1985) reported productivity of 74.3 t/ha/yr by K8 on the moist wastelands at a density of 5000 trees / ha. Although the population density in this experiment was just half of the quoted experiment, yet the low yield in this experiment was mainly attributed to the dry and calcareous degraded lands habitat on which the trees were grown.

Second Rotation

Based on the per tree yield and their respective density, the productivity of different segments viz., wood, leaf, above ground biomass and total biomass are presented in table 4.2.14.

Woody biomass : Production of bole, branch, leaf and litter was recorded during the three years of growth. It showed the maximum current increment during the second year (35.67 t/ha/yr) followed by the first year. The mean increment was also maximum during the second year (24.56 t/ha/yr). A comparison of all the varieties shows similar feature. The peak current increment was observed in S24 during the second year (47.74 t/ha/yr). It followed the trend of the mean productivity in all the varieties. The maximum mean annual productivity was observed in S24 (29.2 t/ha/yr) during the second year. There was a general decline in mean annual production in the third year with the maximum in S24 and the minimum in S22.

Above ground biomass : The total above ground biomass also showed the same trend with maximum current increment during the second year (37.07 t/ha/yr) followed by the first year. The mean increment was also maximum during the second year (26.19 t/ha/yr). The comparison of all the varieties also showed similar feature. The peak current increment was observed in S24 during the second year (49.67 t/ha/yr). It has also followed the trend of mean productivity in all the varieties. The maximum mean annual productivity was observed in S24 (30.78 t/ha/yr) during the second year. There was a general decline in mean annual production in the third year with the maximum in S24 and the minimum in S22 (Table 4.2.14).

Table 4.2.14 : Productivity (t/ha/yr) of *Leucaena leucocephala* varieties.

Variety	Year	Mean annual productivity			Current annual productivity		
		Wood	Above ground	Total	Wood	Above ground	Total
S24	1	11.75	15.30	21.04	11.75	15.30	21.04
	2	29.23	30.78	46.24	46.68	46.36	71.45
	3	24.49	25.85	44.57	15.04	15.99	41.23
S22	1	16.01	19.21	28.63	16.01	19.12	28.63
	2	22.11	24.20	47.35	28.24	29.30	16.06
	3	18.26	19.33	33.91	10.53	9.6	7.06
S14	1	9.95	14.14	21.62	9.95	14.14	21.62
	2	19.81	21.18	37.56	29.70	28.22	53.49
	3	16.36	17.43	32.22	9.43	9.92	20.89
S10	1	21.89	27.37	37.40	21.89	27.37	37.40
	2	25.50	27.22	45.11	29.14	27.06	52.82
	3	24.30	25.75	44.74	21.87	22.82	44.00
K8	1	13.35	16.82	24.79	13.35	16.82	24.79
	2	25.54	26.85	48.14	37.52	36.88	71.49
	3	22.08	23.35	41.19	15.18	16.36	27.29
Mean	1	14.55	18.39	26.70	14.55	18.39	26.70
	2	24.56	26.19	45.36	34.58	33.99	64.02
	3	20.35	21.56	38.11	11.91	12.31	23.61

Total biomass : The current annual increment in total biomass was found to be maximum in the second year (58.02 t/ha/yr) followed by the first year. The mean annual increment was maximum during second year (40.64 t/ha/yr). With respect to the varieties the peak current annual increment was observed in S24 during the second year (66.53 t/ha/yr). It has also followed the trend of mean productivity in all the varieties. The maximum mean annual productivity was observed in S24 (41.96 t/ha/yr). There was also a general decline in mean annual production in the third year with the maximum in K8 and the minimum in S14 (Table 4.2.14).

4.2.11 Energy Storage and its Efficiency

Energy storage and ecological efficiency in different parts of *Leucaena leucocephala* varieties over three years of growth is presented in table 4.2.15. It is apparent from the data that out of the total energy harvested, maximum portion of it was stored in bole followed by the below ground and stump. The allocation of energy diverted towards branch on age of plantation increased than leaf as is evident from table 4.2.16 which is presented as percentage in different parts. At the end of the third year of growth S10 leads in its potentiality to harvest maximum amount of energy followed by S24 as compared to K8 and other selections.

4.2.12 Discussion

Leucaena is considered as one of the fastest growing tropical woody perennial with highest potential for biomass production (NAS 1984). During 1960s and 1980s it was regarded as a miracle tree with potential to provide the most vital needs of rural set up for a sustainable living. During the past 25 years its potentials for fast growth, forage production, firewood production, biomass production, nutritive value, value as protein supplement to the animals, nurse crop, soil amelioration, nitrogen fixation etc. have been worked out extensively.

An attempts made in this investigation to understand the plant processes controlling its growth and biomass production on highly degraded lands involving 5 potential varieties in dry semi-arid zone have given much insight into its versatility. The five varieties used in this study have statistically significant differences amongst

Table 4.2.15 : Energy storage (X 107 K cal / ha) in different components of *L. leucocephala* plantation and its ecological efficiency (%).

Age (Yrs)	Components	VARIETY					Mean
		S24	S22	S14	S10	K8	
1	Bole	4.24	4.99	3.61	7.90	5.06	5.11
	Branch	1.24	2.43	1.04	2.31	1.27	1.67
	Leaf	1.60	1.40	1.88	2.46	1.47	1.73
	Total AG	7.08	8.82	6.53	12.67	7.80	8.51
	BG + Stump	2.43	4.09	3.12	4.24	3.35	3.47
	Litter	0.743	0.68	1.17	1.86	1.25	1.14
	Fine root	0.023	0.0898	0.1557	0.172	0.147	0.172
	Total	10.346	13.68	10.976	18.942	12.547	13.292
	Efficiency	1.169	1.545	1.243	2.14	1.418	1.50
2	Bole	20.20	14.20	12.40	18.70	17.10	16.5
	Branch	3.90	4.00	3.90	2.40	4.00	3.64
	Leaf	1.20	1.70	1.10	1.40	1.00	1.28
	Total AG	25.30	19.90	17.40	22.50	22.10	21.42
	BG + Stump	8.70	15.20	8.91	10.50	12.60	11.18
	Litter	3.16	2.93	3.81	3.40	4.10	3.48
	Fine root	0.398	0.394	0.511	0.492	0.441	0.447
	Total	37.558	38.424	31.321	36.892	39.241	36.527
	Efficiency (mean)	2.122	2.17	1.769	2.08	2.222	2.064
	Efficiency (current)	3.07	2.796	2.23	2.028	3.016	2.63
3	Bole	24.8	15.10	16.5	24.60	22.30	20.66
	Branch	5.5	3.40	3.70	5.50	5.00	4.62
	Leaf	1.65	1.16	1.29	1.76	1.54	1.48
	Total AG	31.95	19.66	21.49	31.86	28.84	26.76
	BG + Stump	17.34	10.48	11.46	17.13	15.60	14.40
	Litter	4.55	4.40	5.62	5.08	5.27	4.98
	Fine root	0.569	0.575	0.742	0.672	0.679	0.647
	Total	54.409	35.115	39.312	54.742	50.389	46.787
	Efficiency (mean)	2.049	1.322	1.481	2.062	1.898	1.762
	Efficiency (current)	1.90	0.37	0.902	2.017	1.26	1.16

Table 4.2.16 : Energy allocation (%) to different parts of the biomass in *L. leucocephala* varieties..

Age (Yrs)	Parts	VARIETY					Mean
		S24	S22	S14	S10	K8	
1	Bole	40.98	36.48	32.89	41.71	40.33	38.44
	Branch	11.99	17.76	9.47	12.20	10.12	12.56
	Leaf	15.46	10.23	17.13	12.99	11.72	13.02
	Total AG	68.24	64.47	59.49	66.89	62.17	64.02
	BG + Stump	23.49	29.9	28.43	22.38	26.70	26.11
	Litter	7.18	4.97	10.66	9.82	9.96	8.58
	Fine root	0.22	0.656	1.42	0.91	1.17	1.29
2	Bole	53.78	36.95	39.59	50.69	43.57	45.17
	Branch	10.38	10.41	12.45	6.50	10.19	9.96
	Leaf	3.19	4.42	3.51	3.79	2.55	3.50
	Total AG	67.36	51.79	55.55	60.99	56.32	58.64
	BG + Stump	23.16	39.56	28.41	28.50	32.11	30.61
	Litter	8.41	7.63	12.16	9.22	10.45	9.53
	Fine root	1.06	1.03	1.63	1.33	1.12	1.22
3	Bole	45.58	43.00	41.97	44.94	44.25	44.16
	Branch	10.10	9.68	9.4	10.05	9.92	9.87
	Leaf	3.03	3.30	3.28	3.21	3.06	3.16
	Total AG	58.72	55.99	54.66	58.20	57.23	57.19
	BG + Stump	31.87	29.84	29.15	31.29	30.96	30.78
	Litter	8.36	12.53	14.29	9.28	10.46	10.64
	Fine root	1.05	1.64	1.89	1.23	111.35	1.38

them for leaf length, number of pinna pairs/leaf length of pinna, number of flowers per head and mimosine percentage in leaf. Similarly different parameters of pod and seed test weight also showed significant variation between the varieties.

Earlier, Pathak *et al.* (1974) suggested existence of ecotype based on the seed and seedling study from different provenances. In another study where seedling characteristic of 30 provenances were subjected to metroglyph analysis, the character association were found significant (Pathak *et al.* 1984). The summer produced seeds

were lighter than the winter ones. But the heaviest seeds in winter were from S22 while in summer they were from S10. Test weight showed minimum variation due to seasons in K8. The low test weight of S24 during summers is ascribed to their very late flowering affecting seed quality. The late formed pods experience ripening due to high temperature and low humidity in summer months.

Plant growth parameters *viz.* collar diameter, dbh and height of these varieties grown on dry habitats when compared to the growth of K8 or K500 on moist sites (Pathak *et al* 1985) show almost 54.8, 50.0 and 96.2% growth respectively. The early growth up to 2-5 years shows 98% lower growth in collar diameter while the height growth was 123.7% of the moist site reported earlier. At 1.5 years collar diameter was 78% of the moist site while the height was only 105%. This shows the low allocation to wood growth and cessation of height growth subsequently on dry degraded lands compared to moist sites. This may also be due to low stand density in this experiment compared to the moist site due to which more resource allocation was to reproductive efforts and litter fall.

Almost all growth parameters showed strong effect of seasons with peak growth during June-September (rainy season). In a monsoon climate with short wet period this is quite logical. In earlier studies on moist sites similar results were reported by Pathak *et al.*(1985). In case of coppice growth which depends upon the health of stump and root resources the first one year coppice growth was much faster compared to the second year. Height growth between December to March in almost all varieties was negligible while collar diameter growth was maximum in S14. During the same period height of clean bole also increased maximum in K8, S14 and S22 due to self pruning.

Comparing early growth on moist site, the mean collar diameter growth of coppice shoots equalled on the dry site. Height and dbh were 164.7 and 119.2% more than the same age of growth on moist site. At 3 years age the cd, dbh and height were 109.2, 116.4 and 122% higher on drier site in this experiment compared to the moist site reported earlier by Pathak *et al* (1985). In contrast to the growth during the first rotation the coppice shoot growth was much higher indicating the benefits of management under coppice systems.

The study has brought out the varietal response to the monthly variations in

the weather parameter including the soil moisture. In all the varieties lowest L/S ratio was in June (end of dry phase) while it was maximum in November (in S14, K8, S10) December (S24) and March (S22). The overall phenology depicted similar behaviour as reported by Kimura *et al.* (1984).

In trees, the current productivity rises to a maximum during the active growth phase but declines with maturity so the average rate continue to rise until the current rate falls to equal it. The age at which these rates equal, varies with species and the site quality. Wastlake (1963) reviewed productivity estimates and gave the value for probable annual average productivity on a fertile site for tropical rain forests to be 50 t/ha/yr. *Eucalyptus* and *Leucaena* are reported to give high productivity in tropics (Table 4.2.17). Earlier studies on potential growth and productivity of may species have shown very high productivity.

Table 4.2.17 : Biomass yield of energy plantations compared to the present study.

Genus	Yield (odt/ha/yr)	Author
1. *Calliandra*	33	Anderson *et al.* (1983)
2. *Eucalyptus*	31 - 58	Anderson *et al.* (1983)
3. *Populus*	4 - 19	Anderson *et al.* (1983)
4. *Acacia nilotica*	30.8	Gurumurthy *et al.* (1986)
5. *Leucaena leucocephala*	40.6	Gurumurthy *et al.* (1986)
K8 (5 years)	74.32	Pathak *et al.* (1985)
K500 (2 years)	48.97	Pathak and Gupta (1987)
Silvi-4 (6 years)	49.77	Pathak and Gupta (1991)
S24 (5 years)	32.12	Pathak and Gupta (1994)
Mean of 5 (1 year)	26.699	Present study
Coppice (2 years)	45.365	Present study
Coppice (3 years)	38.109	Present study

Leucaena is regarded to give a productivity ranging from 40-60 t/ha/yr which is superior to even *Eucalyptus*. Gurumurthy *et al.* (1986) reported 30.8 t/ha/yr productivity for *A. nilotica* energy plantation of 5 years age. The productivity of coppice stands at 1,2 and 3 year growth have shown maximum in year 2 and the minimum for year 1. At year 3 the productivity of 37.87 t/ha/yr is 5.75 t/ha/yr more than the productivity of same stand at 5 year age. Compared to earlier studies

conducted in Jhansi on moist degraded lands the productivity obtained is just half. This could be attributed to dryness of the site, plantation density and the soil nutrients. Compared to the productivity of silvipastures on similar dry areas at 10 year rotation, the mean productivity in the present case is more than 3.7 and 4.4 times at 3 and 2 years respectively.

Leucaena continues to drop leaf litter throughout the year. To this are added the flower litter during Oct.-Dec. and March-April and pod, seed and branch litter during Dec.-March and May-June. In the present study peak production is reported during March followed by May and November. In earlier study on moist sites Pathak and Gupta (1987) reported maximum fall during first year in Dec., Feb. & May-June. In another study in Hawaii Van Den Beldt (1982) reported highest yield during November followed by Feb. In the present study from a dry zone the present shift is in response to intense dryness at high radiation with high ambient temperature forcing leaf to fall. The total annual litter biomass (mean of 5 varieties) was found to be 2.71, 9.76 and 12.54 t/ha during Ist, 2nd and the 3rd year. Comparing with other studies Pathak and Gupta (1987) reported 5.58 t/ha in the 2nd year at 10,000 trees/ha density on moist site. Gill *et al.* (1990) observed increasing litter production from 3 - 6 years in a *Leucaena leucocephala* plantation from 3.3 - 7.2 t/ha at 528 trees / ha density. In the present case the mean density of 22870 trees / ha may be responsible for low litter yield in the first year which was made up in the subsequent years. Van Den Beldt (1982) observed 8.5-8.8 t/ha year litter fall in first year at Hawaii at 10,000 20,000 and 40,000 trees / ha. There was not any significant difference due to plant density. The monsoon climate with strong seasonality of soil moisture and air temperature appears to be responsible for such a high litter fall.

Wood / bark ratio increased with age. In earlier study Pathak and Gupta (1991) observed its decrease in bole from base towards the top and between the varieties. Maximum of 12.71 was reported in K8 while the minimum was in K500 (fodder variety). The present study shows the similar value at 3 years against the earlier reported for 6 years growth.

Comparing the energy storage of plantation (Table 4.2.18) shows that *Leucaena* coppice plantation had capacity to store more energy compared to other studies. The present site falls in dry deciduous forest type where the storage is lower

than the study. Even it compares with *Eucalyptus* plantation on good habitats in India.

Table 4.2.18 : Above ground energy storage (x107 k cal/ha/yr) of plantations

Plantation	Energy storage	Author
Hybrid poplar stubble crop 3 years (Pennsylvania)	81	Ahlich and Hinman (1974)
American Sycamore coppice crop 2 years	3.5	Ahlich and Hinman (1974)
Bamboo (South east Asia)	5.0	Ahlich and Hinman (1974)
Eucalyptus India	16.2	Ahlich and Hinman (1974)
Kenya	8.1	Ahlich and Hinman (1974)
Sub tropical deciduous forests	10.2	Ahlich and Hinman (1974)
Leucaena coppice Yr 1 Yr 2 Yr 3	8.51 10.71 8.92	Present study

Energy fixation efficiency was calculated by using the net yearly solar radiation received on the site. Half of the total solar radiation data for Gwalior (70 km from the site) (885054.4 k cal/m^2/yr) have been used for the calculation considering the availability as PAR (Mani and Rangrajan 1982). Maximum radiation was received during May while the minimum was in December. The radiation during growth period July-October was 56847.46 k cal/m^2/yr compared to summers 70908.9 k cal/m^2/yr (March-June).

A comparison of energy fixation efficiency of different ecosystems shows that the forests have maximum efficiency of 2.2 - 3.5% compared to grasslands (1.67%). The coppice growth on highly degraded site gave 2.63% efficiency for 2nd year production (mean 2.064%). At 3rd year the efficiency declined to 1.762% (with current efficiency of 1.16%) (Table 4.2.19). The low efficiency is ascribed to low stand density and the dry habitat. Still the efficiency compared to the dry shrub forests is many times higher.

Energy flow in the plantations of different varieties of *L. leucocephala* is presented in fig. 4.2.15 to 4.2.20. It is evident from these schematic flow diagrams that the bole contributed maximum to the total net production followed by the below ground and stump. S24 and K8 indicate higher total net production followed by S22.

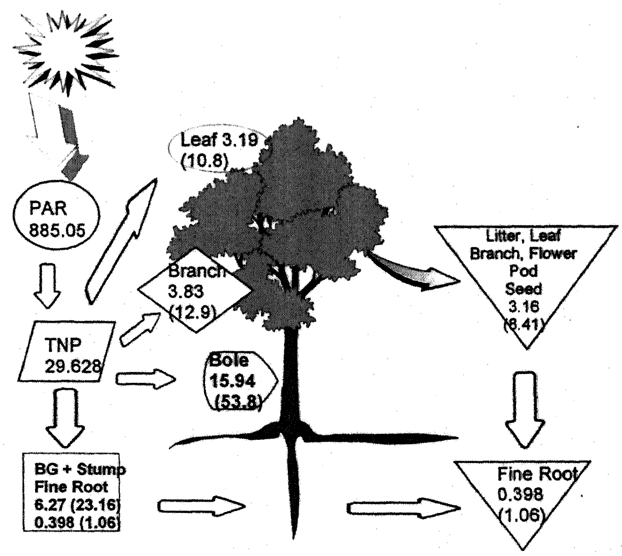


Fig. 4.2.15 : Energy flow in *Leucaena leucocephala (S24)* plantation (M Cal/sq m). values in parentheses are percentage contribution to total net production.

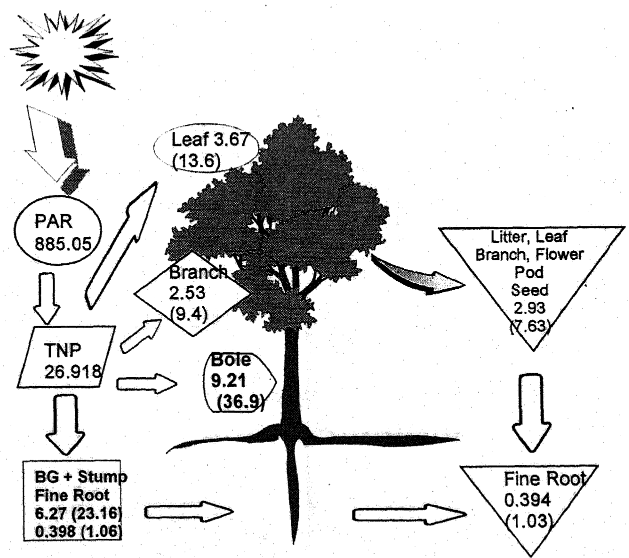


Fig. 4.2.16 : Energy flow in *Leucaena leucocephala (S22)* plantation (M K Cal/sq m). values in parentheses are percentage contribution to total net production.

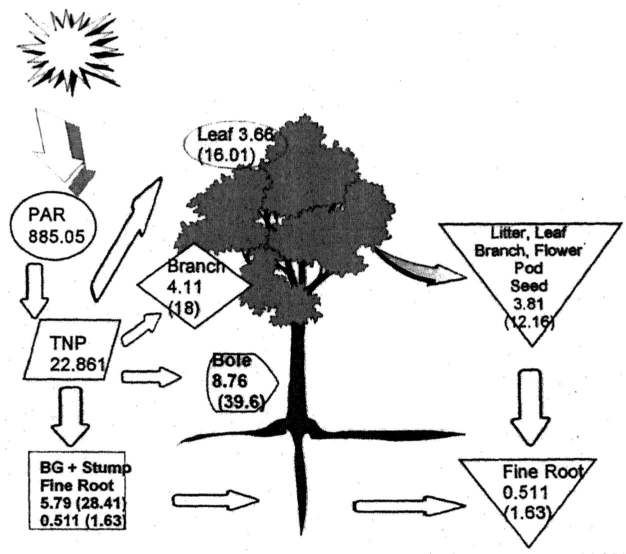


Fig. 4.2.17 : Energy flow in *Leucaena leucocephala (S14)* plantation (M K Cal/sq m). values in parentheses are percentage contribution to total net production.

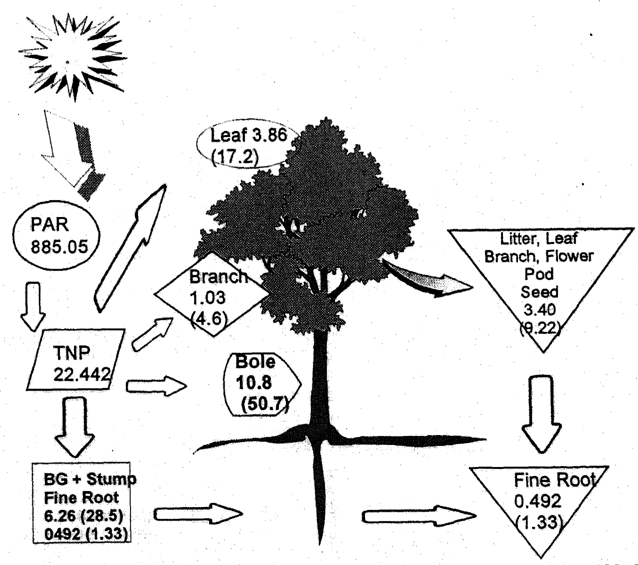


Fig. 4.2.18 : Energy flow in *Leucaena leucocephala (S10)* plantation (M K Cal/sq m). values in parentheses are percentage contribution to total net production.

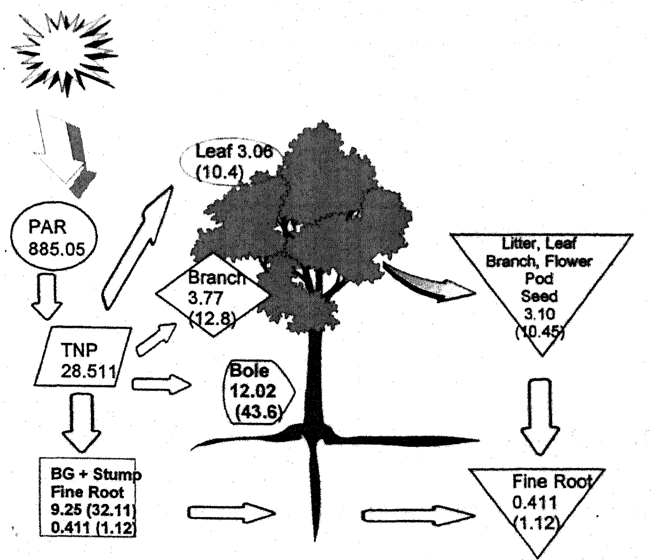


Fig. 4.2.19 : Energy flow in *Leucaena leucocephala (K 8)* plantation (M K Cal/sq m). values in parentheses are percentage contribution to total net production.

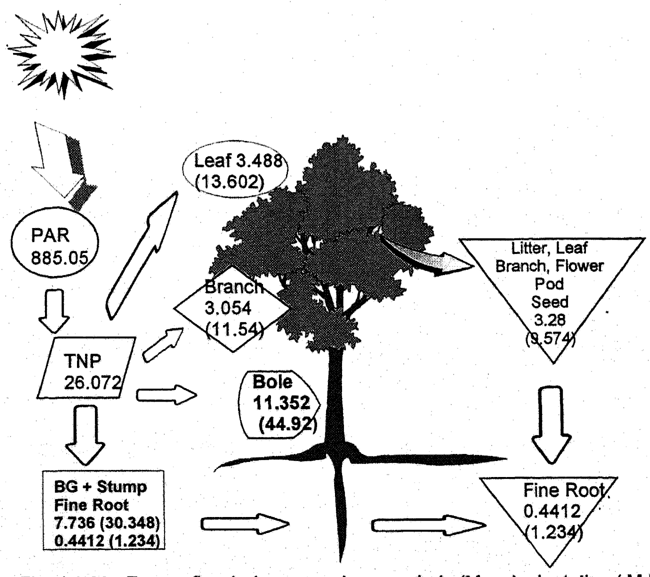


Fig. 4.2.20 : Energy flow in *Leucaena leucocephala (Mean)* plantation (M K Cal/sq m). values in parentheses are percentage contribution to total net production.

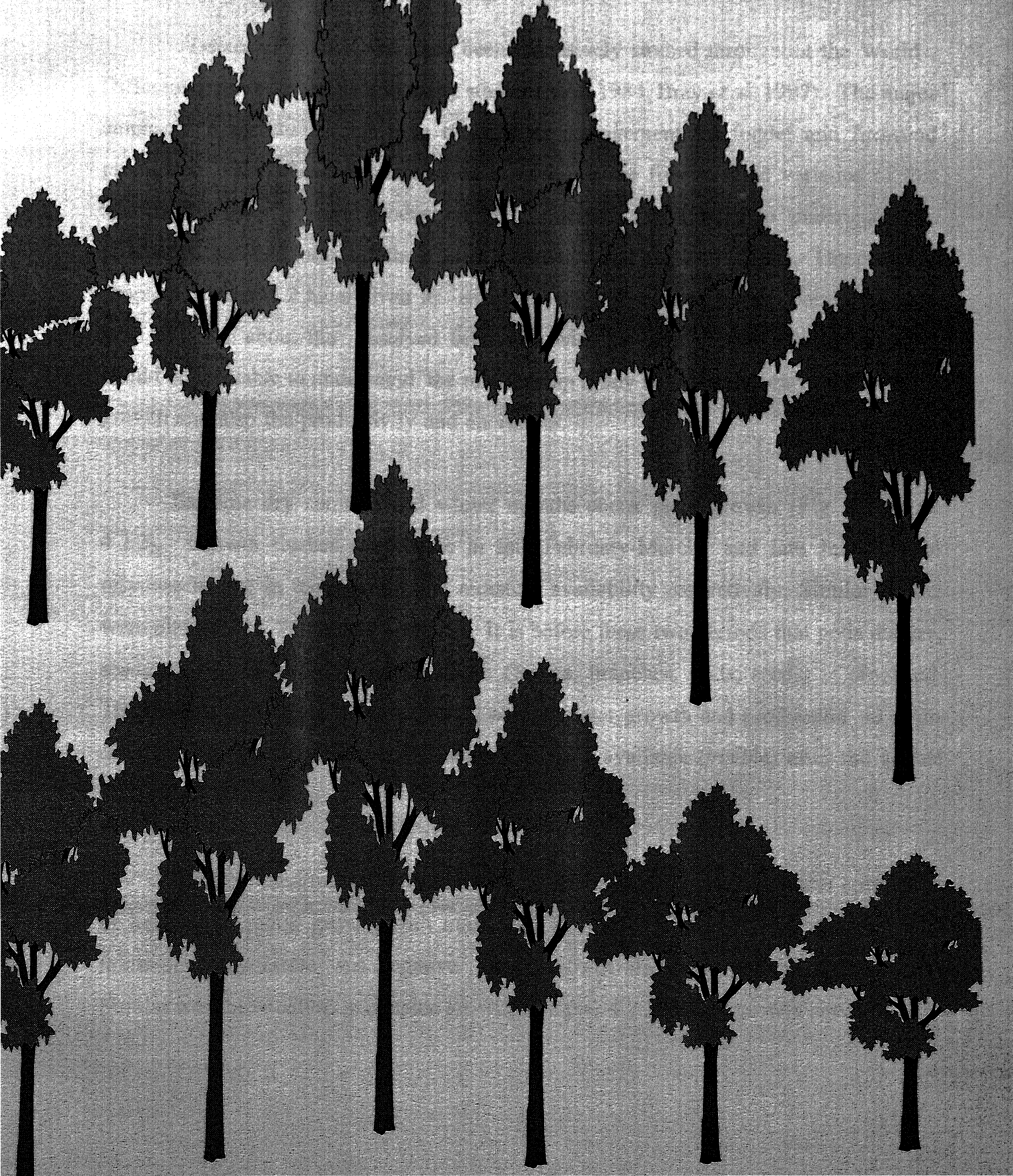
Table 4.2.19 : Comparison of ecological efficiency (%) of net primary production in forests.

Ecosystem	Efficiency	Author
1. Deserts	0.03	Chew and Chew (1965)
2. Forests	2.2 - 3.5	Helmers (1964)
3. Herbaceous vegetation	1.1	Golley (1960)
4. Grasslands at Varanasi	1.67	Singh and Misra (1968)
5. *Leucaena* plantation (mean of 5 varieties)		
1 Year	1.5	Present study
2 Year	2.63	
3 Year	1.16	

S10 and S14 were equal in their net productivity. However, S24 and S10 contribute maximum portion to the total net production indicating their higher wood biomass production potential and may be suitable for plantation in the semi arid environment.

Chapter 5

General Discussion



5
General Discussion

Leucaena leucocephala has been extensively studied throughout the World . Different aspects are detailed in many studies (NAS 1984, Bray *et al.* 1997). The major emphasis in the studies has been towards its management for fodder and firewood production. This thesis has attempted to compare the five selected varieties of this species for their growth, production and energetics and tried to understand the production processes through their direct estimation and growth analysis. The previous chapters 4.1 and 4.2 have given its early growth and coppice growth parameters and tried to argue about the observed behaviour with the help of available literature. It would be desirable to understand the relationship if any between the early and coppice growth and also the productivity and energetics.

Extreme dry summer and winter months check plant growth (Fig. 4.2.1 and 4.2.2). Growth flushes are visible in late February-March and late June-July in response to rise in temperature and moisture availability respectively. Similar results were observed by Pathak *et al.* (1985). It is before these two periods that pods mature, seeds are dispersed and maximum litter (leaves, branches, pods, seeds) is produced. Thus, annual growth in terms of height and diameter growth and production in terms of wood and other biomass components is the net available (visible) after the annual losses from the system.

Effect of environmental factors on growth has shown a positive linear correlation of height and radial growth with maximum air temperature. The relationship with minimum temperature was negative. Root growth also followed the same pattern. Similar was the situation in coppice growth (Chapter 4.2.2) where growth between June-

September was maximum compared to other months. December-March was the period when height growth was almost negligible but the diameter growth was appreciated. This phasic growth in height and diameter is typical to deciduous trees. Varieties showing maximum height and diameter growth (S24, K8, S14 and S22) were also those which gave similar performance in their early growth.

The major advantage of growth analysis is the simplicity of its technology, but the simplicity also limits its resolving power. The techniques of growth analysis were most valuable before newer tools were developed, such as infra-red gas analyzer for measurement of CO_2 exchange, the point hygrometer for measurement of transpiration, and isotopes for assay of translocation and of carboxylating enzymes. However, growth analysis is still a valuable adjust to more sophisticated and costly procedures.

Using classical methods of growth analysis, mean values for RGR, NAR, LAR and other parameters are calculated for the inter harvest period by integral equations. The assumptions involved in choice of computational formula is not always recognized. The use of fitted growth curves to calculate parameters of growth analysis by different formula, a dynamic method, is currently preferred. It leads to no conflicting assumption and has other appealing characteristics, both practical and aesthetic. However, the choice of growth curves may bias results.

Growth analysis provides a relatively simple and inexpensive technique for investigating genetic or environmental effects on growth. Measurements of dry weight and leaf area are made at periodic harvests and used to estimate growth parameters (RGR, RLGR, NAR) or structural parameters (LAR, LWR, SLA, LAI, LAD). Relative growth rate (RGR) may be partitioned among appropriate sets of these parameters. The concepts of growth analysis have been extended to productivity of entire canopies or stands of vegetation by dimension analysis. For trees, periodic harvest and weighing are a major problem and dimension analysis relates weight to easily measured variables such

as dbh using regressions derived from samples. At seedling stage K8 has shown minimum RGR followed by S22 while the peak was in S14. The RGR was negatively correlated with seedling height, diameter and dry weight. This is apparent in the coppice growth too and its biomass production during the years.

Continuation of growth over time is dependent upon several factor including the plant's strategy and functional attributes. A comparison of early growth with coppice and the potential 5 year growth indicates that the early potential height was maintained at 3rd year. Varieties S24 and K8 were top performers in height and diameter growth (Table 5.1). Height growth of potential 5 years also had the same trend. Height and diameter growth variation between the varieties were statistically significant (Table 4.2.3). In the coppice growth, at the end of 1 year, S22 and S10 gave peak performance which changed to S24 and K8 at year 2 and 3. S14 was the poorest in terms of growth. Thus, at 3 years coppice growth, the earlier 5 years growth trend is confirmed. The growth differences during first year were non significant except for the height while during the second year it was the dbh and height that were significantly varying across varieties and the seasons. The first year coppice growth behaviour corresponded with the first year potential growth (Table 5.1).

Table 5.1 : Growth characteristics of *Leucaena leucocephala* varieties at various growth stages.

Variety	Daily growth rate		Growth at 5 yrs.		Coppice growth					
	Height (cm/day)	Diameter (mm/day)	Height (m)	dbh (cm)	Height (m)			Diameter (cm)		
					Yr 1	Yr 2	Yr 3	Yr 1	Yr 2	Yr 3
S 24	0.49	0.62	12.8	9.5	6.38	9.50	10.59	3.55	7.03	9.50
S 22	0.49	0.67	11.7	8.9	6.84	9.20	10.03	3.80	7.53	8.70
S 14	0.49	0.60	12.5	9.9	5.94	8.82	9.30	3.48	6.88	7.70
S 10	0.50	0.56	12.5	10.1	6.54	9.01	10.00	3.59	7.13	8.60
K 8	0.48	0.67	12.8	9.1	6.24	9.41	10.29	3.83	8.40	9.07

Some investigators have found either a weak correlation or none at all between measurements of photosynthesis and growth. The best correlation was reported by Huber and Polster (1955) for some of the clones of poplar *(Populus L.)* which vary in their growth. Frequently there is negative correlation between seedling size and unit photosynthesis (Ledig 1969). A week correlation was reported between photosynthesis and biomass production (Ledig and Botkin 1974). Ledig *et al.* (1976) reported that dry matter production should be related to the total CO_2 fixed during longer period so that the necessary stable conditions exist. Greater size, more leaves and greater depth of the seedling crown result in self shading or a reduction in the average light intensity reaching the leaves (Kramer and Clark 1947). This implies that seedlings with high photosynthetic rate and thus potentially fast growing, experience self-shading sooner than seedlings with low photosynthetic rates, as a result their relative growth rate declines rapidly. In this study also negative correlation of dry matter production with water use efficiency and the carboxylation efficiency during early growth indicates possible losses through leaf fall, reproductive efforts and respiration.

The ecophysiological studies have provided functional aspects of the growth and production of the *Leucaena leucocephala* varieties. The rate of photosynthesis and CO_2 uptake are important components of growth (Ledig and Botkin 1974). Analysis of seasonal pattern of CO_2 exchange of different plant parts may also be useful in constructing physiological models to explain tree growth (Ledig 1969). Because of the potential utility of growth components in plant improvement, it is desirable to quantify genotypes and genotype - environment variations in photosynthesis. The mean photosynthesis rate was maximum in S24 while the lowest was in S10 (Table 5.2). Transpiration rate was maximum in K8 followed by S14 but the differences were non significant (Table 4.1.2). The monthly variations were significant statistically showing the role of ambient temperature and PAR. This behaviour has established higher water use efficiency for S24 followed by S10 and K8. S14 had the poorest water use efficiency. It is further supported by the internal CO_2 concentration.

Carbon balance model has been used to describe plant growth in relation to light and CO_2 levels (Monteith 1965) and experiments under controlled environmental conditions have established a relationship between light and CO_2 exchange (Mc Cree and Troughton 1966). Increased shoot and root respiration and reduced photosynthesis or both may result in NAR decline (Drew and Ledig 1981). The ecological efficiency and production / biomass ratio (P/B ratio) again shows the superiority of S24 followed by K8. S10 was the poorest in efficiency and the P/B ratio.

Table 5.2 : Functional characteristics of *Leucaena leucocephala* varieties.

Variety	Ecological efficiency (%)	Production / Biomass ratio	Water use efficiency (PN/TR)	Net photosynthesis (umol CO_2/m^2/s)	Transpiration (TR) m.mol $H_2O/m^2/s$)	CINT (ppm)	Mimosine content (%)	Seed / Pod weight ratio	
								Winter	Summer
S 24	3.348	0.77	1.59	13.22	8.63	240.56	2.9	1.07	0.749
S 22	3.041	0.70	1.51	11.66	8.49	230.93	3.74	1.032	1.062
S 14	2.583	0.71	1.43	11.92	9.2	237.78	3.71	1.043	1.119
S 10	2.536	0.59	1.58	10.67	7.84	243.45	2.92	1.159	1.24
K 8	3.220	0.74	1.58	11.46	9.0	230.0	3.28	0.937	1.013

Presence of mimosine in leaf is an important characteristics of a variety. S24 was a low mimosine variety while S22 was with the maximum mimosine content. Mimosine and leaf protein are positively associated parameters in these varieties too.

The seed / pod weight ratio indicates biomass wastage from a tree since seeds are collected for planting programmes. The behaviour of this ratio changes with season (Table 5.2). Thus, low ratio in K8 during winter and S24 during summer indicates high wastage by these two varieties during specific seasons. But summer seed

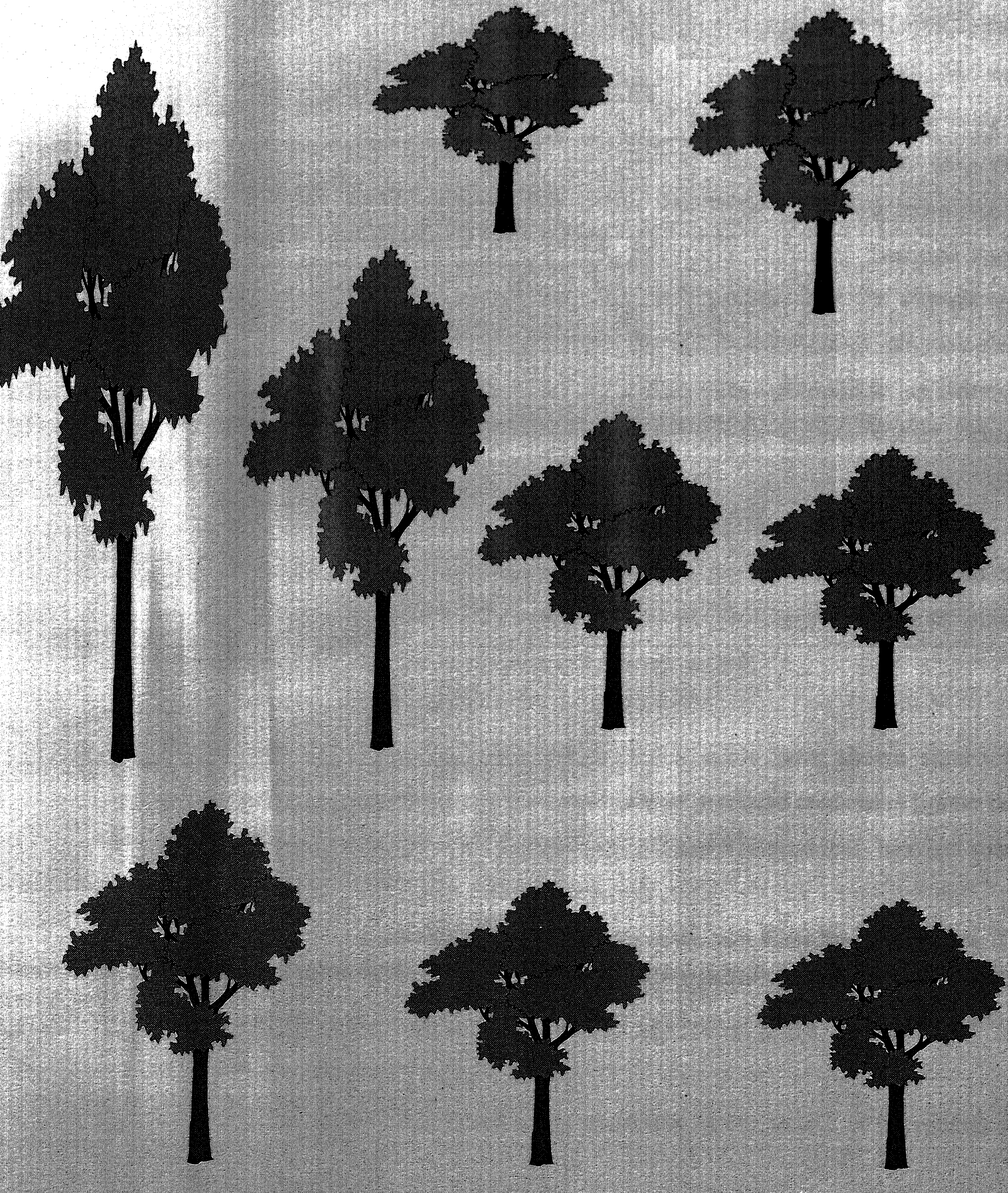
production is very low in S24 compared to K8. S24 being late flowering produces relatively low seed yield too. It is reflected in the test weight of seeds (Table 4.2.2). It is this attribute that impacts capacity to accumulate more wood biomass in S24.

Table 5.3: Biomass production characteristics of *Leucaena leucocephala* varieties

Variety	Biomass production (5 years)		Coppice growth of biomass					
			Ist year		IInd Year		IIIrd Year	
	Bole	Total	Bole	Total	Bole	Total	Bole	Total
S24	39.2	56.36	3.13	7.3	16.96	32.12	20.8	46.7
S22	30.8	44.73	4.198	11.38	13.55	37.5	17.67	40.69
S14	34.3	43.18	2.71	7.59	10.55	26.39	14.12	34.02
S10	36.0	50.16	4.89	10.88	13.18	26.19	17.29	39.28
K8	26.4	41.34	3.81	8.73	14.58	34.02	19.09	43.89

Early growth and biomass accumulation showed its peak in K8 followed by S10 at 1 year, but at year 5 it was in S24 followed by S10 (Table 5.3). K8 remained the lowest. The coppice shoots gave peak in S10 at year one, S22 at year two and S24 in year three. If only bole biomass is seen, it was maximum in S24 at year 2 and 3. Thus, the behaviour of varieties remained almost similar in all the cases. In woody species the first year growth and production although indicates the potential but sustained lead by a variety is only established if losses in form of litter are low in successive years. Ultimate superiority of S24 is the result of such a strategy. It is further supported by the energy flow diagrams (Fig. 4.2.15 - 20) of the varieties. Maximum contribution to bole biomass in S24 and K8 further supports the observations. The plantation has shown higher ecological efficiency as generalized for the forests by Helmers (1964). In this study water use efficiency and ecological efficiency appear to follow similar trend indicating its value (PN/TR) as a predictive tool for estimating the superiority of a variety for higher biomass production.

Chapter 6
Summary



6

SUMMARY

The proposed investigations were carried out on morphological, ecological, physiological and biochemical behaviour of *Leucaena* variants (S24, S22, S14, S10 and K8) to understand their growth behaviour, contributing to the biomass production partitioning and energetics on a rainfed degraded land. These variants were from the final evaluation trial where K8 was used as control. The studies for growth and biomass production of selected *Leucaena* variants were carried out at Central Research Farm (Military Padav area) of the IGFRI, Jhansi (75.35 ^{0}E longitude, 25.27 ^{0}N latitude and 275 m above mean sea level altitude). For early growth, morphological, physiological and biochemical characters the pot culture experiments were conducted at pot culture / experimental house of the Plant Physiology and Biochemistry Section, IGFRI, Jhansi. The salient findings are as under:

1. All the five *Leucaena* varieties were found to be statistically significant for morphological characters like leaf length, number of pinna pairs, length of pinna, number of flower per head and mimosine percentage in leaf.

2. The summer and winter produced pods and seeds have shown significant variation between the varieties and season. The summer produced seeds were lighter than the winter produced seeds. In winter and summer S22 and S10 produced heaviest seeds.

3. In seasonal study the extension growth was maximum from July to October. The rate of relative extension growth was found to be highest at seedling stage. On an average extension growth was maximum in S10 and lowest in K8 variety.

4. The radial growth was found to be maximum in the month of November and

again during January to March. On an average the stem diameter growth of K8 and S24 exceeded to those of S10 and S14. This shows the superiority of K8 and S24 for wood production over S10 and S14.

5. The growth of all the varieties was synchronized with the shoot elongation. The root growth was maximum during favourable growth period (July to October) and minimum in between February and March. K8 attained maximum root length followed by S14.

6. As the plants grow the production of nodule was also found to increase. But in winter it showed decline which may be ascribed to dormancy. S24 and S22 produced maximum number of nodules.

7. The higher leaf turn over rate was in S22, S24, and S14 indicating their higher fodder production than S10 and K8. In winter leaf production was low and in summer it increased showing its dependency over seasonal temperature.

8. The production of branch increased up to March. From April it showed decline due to seasonal dryness. Profuse branching was observed in K8 which led to higher biomass production.

9. The rate of photosynthesis (PN) and stomatal conductance (CS) were higher in S24 exhibiting its higher productivity potential. In general PN, CS, were highest in rainy season and lowest in summer months.

10. The rate of transpiration was maximum in summer and minimum in winter. The variety S24 had minimum rate of transpiration predicting its suitability for dry and arid environmental conditions.

11. Intercellular CO_2 concentration was low in peak growing months exhibiting fast fixation of CO_2 in the course of photosynthesis leading to enhanced productivity.

12. Water use efficiency (ratio of PN/TR) was lowest in summer due to high loss of water vapour. On average S24 had shown its highest water use efficiency indicating its better productivity in dry environment.

13. The carboxylation efficiency (ratio of PN/CINT) was highest in rainy season and was lowest in summer. The maximum carboxylation efficiency of S24 and K8 exhibited their higher productivity potential over other varieties.

14. The total biomass production in term of fresh weight and dry weight was found to increase with the age of plant. Maximum dry matter accumulation was between October-January. Variety K8 had maximum biomass accumulation followed by S24, S10 and S22 as confirmed by relative growth rate of there varieties.

15. Dry matter partitioning was maximum in stem than roots and leaves in all varieties. In early stages of plant growth leaves had maximum biomass accumulation which was decreased with the age of plant. Varieties S24 and S22 partitioned maximum biomass to stem indicating the better wood production potential. This is also evidenced by their Root: Shoot ratio.

16. Leaf area increased with the age of plant. This parameter was found to be closely related with all morphological parameters as evidenced by positive and significant correlation co-efficient with other growth and morphological characters.

17. Specific Leaf Weight (SLW) was found to be related more to seasonal changes. SLW was maximum in S24, S22 and s14 than K8 showing their superiority for higher production. Specific leaf area was maximum during early seedling stage representing

its more contribution in the establishment phase.

18. Leaf Weight Ratio (LWR) and Leaf Area Ratio (LAR) were maximum in the early stage of growth but declined as the leaves attained maturity. Overall selections showed higher LWR over K8 indicating their superiority in foliage biomass production.

19. The photosynthetic pigments in all the varieties were highest in peak growing season and also from April-June, when the flushing of new leaves occurred. Maximum accumulation of chlorophyll content was exhibited by selections than K8 exhibiting their higher photosynthetic efficiency.

20. Nitrate reductase activity (NRA) was found to increase with the age of leaves and as the leaves attained maturity there was a decline. Seasonal influence was more prominent on NRA activity.

21. The carbohydrate content (Sugar and Starch) was influenced with the age of plant and season. The sugar and starch accumulation in stem and roots was more in all the selections than K8 indicating that this stored carbohydrates can be made available for fast coppicing / regeneration. Therefore, these selections were having higher coppicing potentiality .

22. Crude protein content was maximum during growing season in all the varieties. Leaves and root had maximum accumulation of crude protein content than the stem. However, varietal difference were statistically insignificant.

23. Coppice growth was influenced by the season. All varieties had peak growth during June-September (rainy season). The first one year coppice growth was faster as compared to second year. In the coppice growth, lowest Leaf / Stem ratio was in June (end of dry phase) while it was maximum in November, December and March in all the

varieties.

24 The biomass productivity of coppice stands at first, second and third year of growth have shown maximum in second year and minimum in the first year. The mean productivity of coppice stands was found to be more than that of pure stands on same dry land.

25. *Leucaena* continued to drop leaf litter throughout the year. To this, flower litter are added during October-November and March-April and pod, seed and branch litter during December-March and May - June respectively. In the present study peak production was during March followed by May and November.

26. The ratio between wood and bark was found to increase with the age. Maximum ratio was in variety K8 showing its superiority for wood production.

27. Energy storage in different plant parts over 3 years showed maximum allocation to bole during all the three years followed by below ground + stump. S24 and S10 and S14. However S24 and S10 contributed their higher wood biomass production potential and may be suitable for plantation in semi arid environment.

28. During the first year of coppice growth the minimum allocation was to litter biomass while in years 2 and 3 it was to leaf. Allocation to bole increased in 2nd year after which there was a decline.

29. On comparison for energy storage with other plantations, the *Leucaena* coppice plantation had more capacity for energy storage. S24 and S10 had contributed maximum portion of energy to the total net production indicating their high wood biomass production potential and may be suitable for plantation in semi-arid environment for woody biomass production.

Chapter 7

Literature Cited

7
Literature Cited

A. O. A. C. 1960 : *Official Methods of Analysis* (Association of Official Agricultural Chemists), Washington D. C., 9th Edn. p. 643.

A. O. A. C. 1970 : *Official Methods of Analysis of Analytical Chemists*, Inc. Washington D. C., 11th Edn. 54: 128 - 129.

Abrol, Y.P., Kaim, M.S. and Nair, T.V.R. 1976 : Nitrogen assimilation, its mobilization and accumulation in wheat (*Triticum aestivum* L.) grains. *Cereal Research Communications* 4: 431-440.

Ahlich, J. A. Jr. and Hinman, R. E. 1974 : Effective utilization of solar energy to produce clean fuel. *Rep.* National Science Foundation, California.

Ambasht, R.S. and Singh, U.N. 1975 : Energy conserving efficiency of a forest grassland at Varanasi. *Acta Botanica Indica* 3: 132-135.

Anderson, M.C. 1967 : Photonflux, chlorophyll content and photosynthesis under natural conditions. *Ecology* 48: 1050-1053.

Anderson, H.W., Papadopol, C.S. and Zsuffa, L. 1983. Wood energy plantations in temperate climates. *Forest Ecology and Management.* 6: 281-306.

Andrews, M., Sutherland, J.M., Thomas, R.J. and Sprent, J.I. 1984: Distribution of nitrate reductase activity in six legumes: the importance of stem. *New Phytol.* 98: 301-310.

*Angrish, R. 1983: Ph. D. thesis, Punjab University, Chandigarh.

Anon. 1996 : Reports of First National Conference on GREEN INDIA 2047, held at New Delhi, India.

Arora, S. K. and Joshi, U. N. 1986 : Lignification of *Leucaena* leaves during growth and its relationship with mimosine contents. *Leucaena Research Reports* 7: 34 - 35.

Ashton, P.S. 1969: Speciation among tropical forest trees : some deductions in the light of recent evidence. *Biological Journal of the Linnean Society* 1: 155-196.

Aslam, M. and Huffaker, R.C. 1984: Deficiency of nitrate reductase on soluble carbohydrates in primary leaves of Barley under aerobic conditions. *Plant Physiol.* 73: 623-628.

Atkins, C.A., Pate, J.S. and Layzell, D.B. 1979: Assimilation and transport of nitrogen in non- nodulated (NO_3 grown) *Lupinus albus L. Plant Physiol.* 64: 1078-1082.

Babalola, O., Boersma, L. and Youngberg, C.T. 1968: Photosynthesis and transpiration of Montery pine seedlings as a function of soil water suction and soil temperature. *Plant Physiol.* 43: 515-521.

Bandara, M. M. S. P. K. and Gunasena, H. P. M. 1988 : Effect of phosphorus and potassium on foliage yield, mimosine and protein contents on *Leucaena leucocephala. Leucaena Research Reports* 9: 92.

Bar Akiva, A. and Sterbaum, J. 1965: Nitrate reduction in Cetrus tree leaves. *Plant and Soil* 23: 141 - 144.

Bawa, K.S. 1983: *Pattern of flowering in tropical plants. Handbook of Experimental Pollination Biology* (eds. Jones, C.E. and Little, R.J.), 394-410, Van Nostrand Reinhold, NY.

Beevers, L. and Cooper, J.P. 1964: Influence of temperature on growth and metabolism on rye grass. I. Seedling growth and yield components. *Crop Sci.* 4: 139.

Beevers, L. and Hageman, R.H. 1969. Nitrate reductase in higher plants. *Plant Physiol.* 20: 495-522.

Beevers, L. and Hageman, R.H. 1980: Uptake and reduction of nitrate: Bacteria and higher plants - In: , *Encyclopedia of Plant Physiology* (eds. Lauchli, A. and R.L. Bieleski, R.L.), 15A: 351-375, Springer - Verlag, Berlin.

Bell, A.D. 1984: *Dynamic morphology : a contribution to plant population ecology* (eds. Dirzo, R. and Sarukhan, J.) pp. 48-65, Sunderland, Mass. : Sinauer Associates Inc.

Bemberg, S.A., Vollmer, A.T., Kleinkoff, G.E. and Ackerman, T.L. 1967: A comparision of seasonal primary productivity of Mojeve shrubs during wet and dry years. *Amer. Mid. Nat* 95: 398.

Bhatt, R.K. 1989: Seasonal patterns of photosynthetic and water use efficiency in broad leaf forage tree species. *Indian J. Plant Physiol.* 32: 195-199.

Bhatt, R.K. 1990: Growth behaviour of three broad leaf forage tree species. *J. Tree Sci.* 9(1): 12-15.

Bhatt, R.K. and Sinha, N.C. 1990: Photosynthetic pigments -. a prerequisite of grass productivity. *Photosynthetica* 24(1): 147-150.

Bhatt, R.K. 1992: Fodder and biomass production of *Prunus, Celtis and Grewia. Range Mgmt. & Agroforestry* 13(1): 93-96.

Bhatt, R. K. and Misra, L.P. 1990 : Biomass accumulation and light utilization efficiency in genotypes of *Cenchrus. Indian J. Plant Physiol.* 33 (1): 27 - 31.

Bhatt, R.K., Misra, L.P. and Pathak, P.S. 1994: Transpiration and stomatal conductance of grass species under *Leucaena* based silvipastoral system. *Range Mgmt. & Agroforestry* 15(1): 87-92.

Billore, S.K. 1973: Net primary production and energetics of a grassland ecosystem at Ratlam, India. Ph.D. Thesis, Vikram University, Ujjain.

Billore, S.K. and Mall, L.P. 1976: Seasonal variation in chlorophyll content of a grassland community. *Trop. Ecol.* 17: 39-44.

Bisht, R.P., Verma, K.R. and Toky, O.P. 1986: Phenology of evergreen vs deciduous trees of central Himalaya. *J. Tree Sci.* 5(2): 126-130.

Bjorkman, O. 1966: Comparative studies of photosynthesis and respiration in ecological races. *Brittonics* 18: 214.

Bjorkman, O., Gauhl, E., Hiesey, W.M., Nicholson, E. and Nobs, M.A. 1968: Growth of *Mimulus*,

Marchantia and *Zea* under different oxygen and CO_2 levels. *Carnegie Institution Year Book*, 67:477.

Bjorkman, O., Nobs, M., Mooney, H. A., Troughton, J., Berry, J., Nicholson, F. and Ward, W. 1974 : Growth response of plants from habitat with contrasting thermal environments. Transplant studies in the depth valley and the Bodge Head Experimental Gardens. *Carnegie Institution, Year Book*, 73: 757.

Bjorkman, O., Pearcy, R.W., Harrison, A.T. and Mooney, H.A. 1972: Photosynthetic adaptation to high temperatures: a field study in death valley, California. *Science* 175: 786-9.

Boaler, S.B. 1966: Ecology of Miombo site, Lupa North forest reserve, Tanzania, II. Plant communities and seasonal variations in vegetation. *J.Ecol.* 54: 465-479.

Boojh, R. and Ramakrishnan, P.S. 1981: Phenology of trees in a subtropical evergreen montane forests in north east India. *Geo-Eco-Trop.* 5(8): 189-209.

Bourdeau, P.F. and Morgen, F. 1959: Photosynthesis and respiration in colchicine induced polyploid, seedlings of slash pine. *J. Forest.* 57: 191-193.

Bougham, R.W. 1960: The relationship between the critical leaf area, total chlorophyll content and maximum growth rate of some pasture and crop plants. *Ann. Bot.* New series 24: 463-474.

Bowes, G., Ogren, W.L. and R.H. Hageman. 1972: Light saturation, photosynthesis rate, RuDP carboxylase activity and specific leaf weight in soyabeans grown under different light intensities. *Crop Sci.* 12: 77-79.

Braekke, F.H. and Kozlowski, T.T. 1975: Effect of climatic and edaphic factors on radial stem growth of *Pinus resinosa* and *Betula papyrifera* in northern Wisconsin. *Adv. Front. Pl. Sci.* 30: 201-221.

Bray, J.R. 1960: The chlorophyll content of some native and managed plant communities in central Minnesota. *Canadian J. Bot.* 38: 313-333.

Bray, J.R. and Gorham, E. 1964: Litter production in the forests of the world. *Adv. Ecol. Res.* 2: 101-157.

Bray, R. A., Hughes, C. E., Brewbaker, J. L., Hanson, Jean, Thomas, B. D. and Ortiz, Amanda. 1997 : The world *Leucaena* catalouge, Department of Agriculture, The University of Queensland, Australia, 48 pp. + PC diskette.

Breman, H. and Kessler, J.J. 1995: *Woody plants in agroecosystems of semi-arid regions.* pp 340, Springer- Verlog, Berlin - Heidelberg.

Brewbaker, J. L. and Steve Kaye. 1981 : Mimosine variations in species of the genus *Leucaena. Leucaena Research Reports.* 2: 66 - 68.

Brewbaker, J. L. and Sorenson, C. T. 1990 : New tree crops from interspecific *Leucaena* hybrids. In (Janick, J. and Simon, J. E. eds.): *Advances in New Crops*, Timber Press, Portland pp 283 - 289.

Brewbaker, J. L., Hegde, N., Hutton, E. M., Jones, R. J., Lowry, J. B., Moog, F. and Van den Beldt, R. J. 1985: *Leucaena - Forage Production and Use*, NFTA, Hawaii, 39 pp.

Briggs, G.M., Jurik, T.W. and Gates D.M. 1986: Non stomatal limitations of CO2 assimilation in three, tree species during natural drought conditions. *Physiol. Plant.* 66: 521-526.

*Brix, H.C. 1962: *Physiol. pl.* 15:10.

Campbell, G.S. and Norman, J.M. 1989: The description and measurement of plant canopy structure. In: *Plant Canopies : their growth form and function.* pp. 1-20 (eds. Russel, Marshall and Jarvis), Cambridge university Press.

Chabot, B.F. and Chabot, F.J. 1977: Effect of light and temperature on leaf anatomy and photosynthesis in *Fragaria vesca. Oecologia* 26(4): 363-377.

Chapman, S.B. 1976: Production ecology and nutrient budget. p. 157-228. In: (Chapman, S.B. ed.) *Methods in Plant Ecology.* Blackwell, Oxford.

Chaturvedi, O.P. and Singh, J.S. 1987 a: The structure and function of Pine forest in central Himalaya. I. Dry matter dynamics. *Annals of Botany* 60: 237-252.

Chaturvedi, O.P. and Singh, J.S. 1987 b: The structure and function of pine forest in crentral Himalaya. II. Nutrient dynamics. *Ann. Bot.* 60: 252-267.

Chaudhry, A. R. and Ahmad, K. 1990: Performance of *Leucaena* cultivars under irrigated conditions. *Leucaena Research Reports* 11: 107 - 108.

Chew, R. M. and Chew, A. E. 1965 : The primary productivity of a desert shrub (*Larrea tridentata*) community, *Ecol. Mongr.* 35 : 355 - 375.

Choudhury, K.A. 1964: Growth rings in tropical trees and economy. *J. Indian Bot. Soc.* 43: 334-342.

Choudhary, V.B. 1967: Seasonal variation in standing crop and energetics of *Dichanthium annulatum* grassland at Varanasi. Ph. D. thesis, Banaras Hindu University, Varanasi, India.

Choudhary, V.B. 1972: Seasonal variation in standing crop and net aboveground production in *Dichanthium annulatum* grassland at Varanasi. In: (Golley, P.M. and F.B. Golley, F.B. eds.) *Symp. Tropical Ecology with emphasis on organic production,* 51-57, International Soc. for Trop. Ecol., University Georgia, Athens, USA.

Choudhary, V.B. 1974: Energy values and efficiency of net primary production in one year old stand of *Dichanthium annulatum* grassland. *Trop. Ecol.* 15(1,2): 52-60.

Claussen, W. 1986: Influence of fruit load and environmental factors on nitrate reductase activity and on concentration of nitrate and carbohydrates in leaves of egg plant (*Solanum melongena*) *Physiol. Planta.* 67:73-80.

Cooper, Allen. 1982: Litter fall and decomposition in tropical xeromorphic woodlands and scrub. *Trop. Ecol.* 23(2): 193-207.

Crafts, Brandner, Below, S.J., Harper, F.E., J.E. and Hageman, R.H. 1983: Metabolism of carbon and nitrogen by Soyabean seedlings in response to vegetative apex removal. *Plant Physiol.* 73: 6-9.

Croat, T.B. 1975: Phenological behaviour of habit and habitat classes on Barro Colorado Island (Panama

Canal Zone). *Biotropica* 7: 270-277.

Daubenmire, R. 1972: Phenology and other characteristics of tropical semi deciduous forest in north western Costa Rica. *J. Ecol.* 60: 147-170.

Dadykin, V.P. and Bedenko, V.P. 1961: The connection of the optical properties of plant leaves with soil moisture. *Dokl. Acad. Sci.* USSR 134(1-6): 212-214.

Davidson, R.L. 1969: Effect of root / leaf temperature differential as root shoot ratios in some pasture grasses and Clover. Ibid, 33: 561-569.

Davies, S.J.J.F. 1976: Studies of the flowering season and fruit production of some arid zone shrubs and trees in western Australia. *J.Ecol.* 64: 665-687.

Dejong, T.M., Tombesi, A. and Ryugo, K. 1984: Photosynthetic efficiency of Kiwi (*Actinidia chinensis* Planch.) in response to nitrogen deficiency. *Photosynthetica* 18: 139-145.

de lucena Costa, Newton and Valdinei Tadeau Paulino 1990: Effect of liming and phosphorus application on growth, mineral composition and nodulation of *Leucaena. Leucaena Research Reports* 11: 39 - 41.

Desai, S. N., Desale, J. S., Khot, R. B. and Patil, S. K. 1988: Effect of phosphorus and potash fertilizer on the forage production of *Leucaena leucocephala .Leucaena Research Reports* 9: 46.

Desh Bandhu 1970: A study of the productive structure of northern tropical deciduous forests near Varanasi. I. Stand structure and non-photosynthetic biomass. *Trop. Ecol.* 11(1): 90-104.

De wit, C.T. 1960: Photosynthesis of leaf canopies. *Agric. Res. Rep.* 663: 1-47.

Dhyani, P.P., Purohit, K.D. and Purohit, A.N. 1986: Resource availability and plant antiherbirone defence. *Proc. Indian Acad. Sci.* B 52(5): 665-672.

Dhyani, P.P., Purohit, A.N. and Negi, D.C.S. 1988: Leaf surface temperature differences and thermal conductivity of leaves in some tropical mountain plant species under their natural environment. *Proc. Indian National Sci. Acad.* 54B: 283-286.

Dhyani, P.P. 1989: Transpiration and energy exchange in the leaves of *Populus x euramericana* Guinier and *Alnus nepalensis* Don. at different altitudes. *Trop. Ecol.* 30(1): 58-64.

Doherenwend, R.E. 1969: Crown shape and stand structure as a function of latitudinal variation in the terms of radiation budget - term paper, G.F. 798, State College of Forestry, Syracuse.

Downes, R.W. 1970: Effect of light intensity and leaf temperature on photosynthesis and transpiration in wheat and sorghum. *Australian J. Biol. Sci.* 23: 775-782.

Drew, A.P., Drew, L.G. and Fritts, H.C. 1972: Environmental control of stomatal activity in mature semi-arid site ponderosa pine. *Arizona Acad. Sci.* 7: 85-93.

Drew, A.P. and Ledig, F.T. 1981: Seasonal patterns of CO_2 exchange in the shoot and root of Loblolly pine seedlings. *Bot. Gaz.* 142(2): 200-205.

Duthie, J. F. 1960 : Flora of Upper Gangetic plain, Vol. I & II, pp. 568 & 450, Government of India Press, Calcutta (reprinted).

Dutt, A. K. and Jamwal, Urmila 1987: Effect of coppicing at different heights on wood production in *Leucaena*. *Leucaena Research Reports* 8: 27 - 28.

Dwivedi, R.S. 1971: Suitability of measuring carbon assimilation rates for evaluation of solar energy conservation and dry matter production in plants.*Trop. Ecol.* 12(1): 123-132.

Duxbury, A. C. and Yentsch, C. S. 1956: Plankton pigment monographs, *J. Marine Research* 15: 92 - 101.

Eaton, F. M. and Ergle, D. R. 1952: Fiber properties and carbohydrates and nitrogen levels as affected by moisture supply and fruit fulness. *Plant Physiol.* 27: 541 - 562.

Egle, K. 1960: Menge and verhaltnis der pigmente. In: (Ruheland, W. ed.) *Handbook der Pflanzenphysiologie,* Vol. VII: 444-496, Springer - Verlag, Berlin - Gottingen - Heidelberg.

Evans, G.C. 1972: *The Quantitative Analysis of Plant Growth.* Univ. california press, Berkeley and Los Angles calif. pp. 734.

Evans, J.R. 1993: Photosynthetic acclimation and nitrogen partitioning within a *Lucerne* canopy. I. Canopy characteristics. *Australian J. Plant Physiol.* 20: 55-67.

Ezenwa, I. V. 1994: Cutting management influence on ash contents of *Leucaena* and *Gliricidia* leaves. *Nitrogen Fixing Tree Research Reports* 12: 10 - 12.

Ezenwa, I. V. and Cobbina, J. 1991 : Relative importance of different nutrient elements and rhizobium inoculation for early growth of *Leucaena. Leucaena Research Reports* 12: 72 - 74.

Farquhar, G.D. and Sharkey, T.D. 1982: Stomatal conductance and photosynthesis. *Ann. Rev. Plant Physiol.* 33: 317-345.

Fernandez, O.A. and Caldwell, M.M. 1975: Phenology and dynamics of root growth of three cool semi-desert shrubs. *J. Ecol.* 63: 703-714.

Field, C.B., Ball, J.T. and Berry, J.A. 1989: Photosynthesis: Principles and yield techniques, In: (Ehleringer, J., Mooney, H.A. and Rundel, P.W. eds.) *Plant Physiological Ecology - field methods and instrumentation.* 209-253, Chapman and Hall.

Fisher, R. A. and Yates, Frank 1963 : *Statistical Tables for Biological, Agriculture and Medical Research.* 6th Edn. Oliver and Boyel. Edinburgh Tweeddale Court.

Fock, H., Krotkov, G. and Canvin, D.T. 1969: Photorespiration in liverworts and leaves. In; (vietzer, H. ed.) *Progress in Photosynthesis Research* I: 482.

Frankie, G.W., baker, H.G. and Oplar, P.A. 1974: Comparative phenological studies in trees in tropical wet and dry forests in the low lands of Costa Rica. *J. Eco*l 62: 881-919.

Friend, D. J. C., Perry, M. H. and Yamamoto, H. Y. 1988 : Shade adaptation of photosynthesis and growth of seedlings of wild and giant cultivars of *Leucaena leucocephala. Leucaena Research Reports* 9: 115 - 122.

Gaastra, P. 1959: Photosynthesis of crop plants as influenced by light, CO_2, temperature and stomatal diffusion resistance. Meded land Hogesch Wageningen. 5913): 1-68.

Gates, D.M. 1962: *Energy exchange in the biosphere*. Harper and Row, N.Y. and John Weather Hill, Inc., Tokyo: 1-151pp.

Gates, D.M. and Benedick, C.M. 1963: Convection phenomenon from plants in still air. *Am. J. Bot.* 50: 563-573.

Gates, D.M. 1975: In: (Gates, D.M. and Schmerl, R.B. eds.) *Perspectives of Biological Ecology*, Springer - Verlag, Berlin - Heidelberg - New York.

Gates, D.M. 1976: Energy exchange and transpiration, In:)Lange, O.L., Kappen, L. and Schulze, E.D. eds.) *Water and Plant Life : Problems and Modern Approaches*, Springer - Verlag, New York, 139 pp.

Gates, D.M. 1980: *Biophysical Ecology*, Ist Edition, Springer - Verlag, New York.

Gessner, R. 1949: Die chlorophyllgehalt in see and seine photosynthetische Valenz als geophysikalishes problem schweizerische Zeitschrift fur. Hydrologic 11: 378-410.

Gill, H. S., Rao, D. L. N. and Abrol, I. P. 1990 : Litter yield and its quality in plantations of *Leucaena leucocephala* and *Sesbania sesban* in alkaline soils. In : (Pathak, P. S., DebRoy, R. and Singh, P. eds.) *Multipurpose Tree Species for Agroforestry Systems*, 187 - 196, Range Management Society of India, Jhansi.

Golley, F.B. 1961: Energy values of ecological materials. *Ecology* 581-584.

Golley, F.B. 1965: Structure and function of old field broomsedge community, *Ecological Monograph* 35: 113-137.

Golley, F.B. 1969: Caloric value of wet tropical forest vegetation. *Ecology* 50(3): 517-519.

Goodchild, O.J., Bjorkman, O. and Phyliotis, N.A. 1972: Chloroplast ultrastructure, leaf anatomy and content of chlorophyll and soluble protein in rain forest species. Carnegi Inst. Washington *Year Book*, 71:20.

Gopal, M. 1972: A mathematical approach to photosynthesis and growth of tree species. *Indian For.* 198: 387-401.

Grace, J., Fasehum, F.E. and Dixon, M. 1980: Boundary layer conductance of leaves of some tropical timber trees. *Plant Cell and Environment* 3: 443-450.

Grace, J., Ford, E. D. and Jarvis, P. G. 1981 : *Plants and their Atmospheric Environment*. Blackwell Scientific Publ. Oxford - London - Edinburgh.

Gupta, B. K., Ahuja, A. K. and Malik, N. S. 1992 : *Leucaena* leaves as high protein substitute for de-oiled seed cake in concentrates for dairy cattle in India. *Leucaena Research Reports* 13: 24 - 25.

Gupta, R. K. 1983 : Establishment and management of fodder trees in sub temperate regions. In (Singh, Manohar ed.) *Topfeed Resources their Production, Utilization and the Constraints*, 20 - 41,

CSWRI, Avikanagar.

Gupta, S.K. 1972: Energy structure of standing crop in certain grasslands at Gyanpur. *Trop. Ecol.* 13(1): 89-95.

Gupta, S.K., Pathak, P.S. and Deb Roy, R. 1983: Biomass production of *Sesbania sesban* Pers. on different habitats. *My Forest* 19(3): 145-155.

Gupta, S.R., Amita and Rout, S.K. 1988: Integration of trees, crops and livestock in *Populus - Leucaena* agroforestry system. In: (Singh, P., Shankar, V. and Srivastava, A.K. eds.) *Abstracts, Third International Rangelands Congress*, 509-511. Range Management Society of India, IGFRI, Jhansi.

Gupta, V. K., Kewalramani, N., Ramchandra, K. S. and Upadhyay, V. S. 1986 : Evaluation of *Leucaena* species and hybrids in relation to growth and chemical composition. *Leucaena Research Reports* 7: 43 - 45.

Gurumurthy, K., Bhandari, H. C. S. and Dhawan, H. 1986 : Studies on yield, nutrients and energy conversion efficiency in energy plantations of *Acacia nilotica. J. tree Sci.* 5(1): 36 - 42.

*Hadley, E.B. and Bliss, L.C. 1964: *Ecol. Monogr.* 34:331-357.

Halle, F. and Martin, R. 1968: Study of growth rhythym in *Hevea brasiliensis* (Euphorbiaceae - Crotonidae). *Adansonia* 8: 475-503.

Hall, A.E. and Bjorkman, O. 1975: Model of leaf photosynthesis and transpiration. In: (Gates, D.M. and Schmeri, R.B. eds.) *Perspectives of Biophysical Ecology,* 55-72, Springer - Verlag, Berlin - Heidelberg, New York.

Halle, F., Oldemann, R.A.A. and Tomlinson, P.B. 1978: *Tropical Trees and Forests*, Springer - Verlag, Berlin - Heidelberg - New York.

Han, Qingmin and Kakubari, Y. 1996: Drought dependent response of photosynthesis, transpiration and water use efficiency of Japanese Cypress and Japanese red pine seedlings. *J.For. Res.* 1: 73 - 78.

Harada, H., Satoo, H., Hottiya and Tadaki, Y. 1972: Study on the nutrient contents of mature *Cryptomeria* forest. *Bull. Govt. Forest Expt. Station,* Tokyo 249: 17 - 74.

Harper, J.E., Nicholas, J.C. and Hageman, R.H. 1972: Seasonal and canopy variation in nitrate reductase activity of Soyabean (*Glycine max* L. Merr.) varieties. *Crop Science* 12: 382 - 386.

Harper, J.L. 1984: Introductory comments. In: (Dirzo, R. and Sarukhan, J. eds.) *Perspectives of Plant Population Ecology,* 15 - 17, Sunderland, Massachusetts: Sinauer Associates Inc.

Harper, J. L. 1989 : *Plant Canopies : their Growth, Form and Function.* eds. Russel, G., Marshall, B. and Jarvis, P. G., 105 - 128, Cambridge University Press.

Harper, J.L., Jones, M. and Hamilton Sackville, N.R. 1991: The evolution of roots and the problems of analysing their behaviour. In: (Atkinson, D. ed.) *Plant Root Growth: an Ecological perspective,* 3 - 24, Blackwell Scientific Publications.

Haseba, Tetsuya, Os a, Takechi mu and Daijirotto. 1967: Studies of transpiration in relation to the

environment : annual changes in transpiration from *Citrus* leaves. *J. Agr. Meteorol.* 23(1): 19-24.

Hasio, T.C., Acivedo, E. and Henderson, D.W. 1970: *Gates Biophysical Ecology*. Springer - Verlag, New York. 215 - 225.

Hasio, T.C. 1973: Plant responses to water stress. *Ann. Rev. Plant Physiol.* 24: 519-570.

Hauad Marroquin, L. A. and Foroughbakhch, R. 1991 : Variation in mimosine content among three soecies of *Leucaena* in eastern Nuevo Leon, Mexico. *Leucaena Research Reports* 12: 63 - 65.

Hauffaker, R.C., T. Redin, Kleinkopf, G.E. and Cox, C.L. 1979: Effects of mild water stress on enzymes of nitrate assimilation and the carboxylative phase of photosynthesis in Barley. *Crop Sci.* 10: 471 - 474.

Havranek, W. 1972: Uber die Bedeutung der Boden temperature fur die photosynthesis and transpiration junger Forstpflanzen und di toffproduktion an der waldgrenze. *Angewandte Botanik* 46: 101- 116.

Havranek, W.M. and Benecke, V. 1978: The influence of soil moisture on water potential, transpiration and photosynthesis of conifer seedlings. *Plant and Soil* 49: 91 - 103.

Heath, O.V.S. and Orchard, B. 1957: Temperature effects on the minimum intercellular space carbon di oxide concentrations. I. *Nature* (London) 180: 180 - 181.

Heath, O.V.S. 1969: *The Physiological Aspects of Photosynthesis*. London, Heinemann.

Helmers, H. 1964 : An evaluation of photosynthetic efficiency of forests, *Quart. Rev. Biol.* 39: 249 - 259.

Hiesey, W.M., Nobs, M.A. and Bjorkman, O. 1971: Experimental studies on the nature of species. V. Biosystematics, genetics and physiological ecology of the *Erythranthe* section of *Mimulus.* Carnegie Instn. Washington No. 628: VI. 210.

Hirekerur, L. R., Lal, S. and Pofali, R. M. 1990 : Approaches to development planning for degraded lands. In : *Technologies for Wastelands Development*, 43 - 58, ICAR, New Delhi.

Hilty, S.L. 1980: Flowering and fruiting periodicity in a pre-montane rain forest in Pacific Columbia. *Biotropica* 13: 292 - 306.

Holway, J. C. 1965 : Phenology of alpine plants in northern Colorado. *Ecology* 46: 73 - 83.

Horn, H.S. 1971: *The Adaptive Geometry of Trees*. Princeton Univ. Press, Princeton.

Hu, Ta-Wei, Cheng, Wei-Er and Shen, Tse-An. 1983 ; Nutrient accumulation of *Leucaena leucocephala* with different planting spacings. *Leucaena Research Reports* 4: 71 - 72.

Hu, Ta - Wei and Tao Kiang 1982 : Wood production of spacing trial of *Leucaena* in Taiwan, *Leucaena Research Reports* 3: 59 - 61.

Huber, B. and Polster, H. 1955: Zur frage der Physiologischen Ursachen der unterschiedlichen stofferzeugung von papplkhen. *Biol. Zentralbl.* 74: 370 - 420.

Hughes, C. E. 1993 : *Leucaena* genetic resources - the OFI *Leucaena* seed collection and a synopsis of

species characteristics. Oxford Forestry Institute, Oxford, U. K.

Hughes, G., Keatinge, J.D.H., Cooper, P.J.M. and Dee, N.F. 1987: Solar radiation interception and utilization by chickpea (*Cicer arietinum* L.) crops in northern Syria. *J. Agricultural Sci.* Cambridge 108: 419 - 424.

Hussain, A., Hussain, A., Chugtai, F. A. and Javed, M. 1988 : Effect of macro and micronutrients on the growth of *Leucaena leucocephala. Leucaena Research Reports* 9 : 80 - 81.

Isarasenee, A., Shelton, H. M. and Jones, R. M. 1984 : Accumulation of edible forage of *Leucaena leucocephala* cv. Peru over late summer and autumn for use as dry season feed. *Leucaena Research Reports* 5: 3 - 4.

Jackson, J.F. 1978: Seasonality of flowering and leaf fall in a Brazalian sub tropical lower montane moist forest. *Biotropica* 10: 38 - 42.

Jain, P. M. and Beniwal, R. K. 1983 : Top feed resources in the semiarid regions. In (Singh, Manohar ed.) *Topfeed Resources, their Production, Utilization and Constraints,* 1 - 13.

Janzen, D.H. 1978: Seedling pattern of tropical trees, In: (Tomlinson, P.B. and Zimmerman, M.H. eds.) *Tropical Trees as Living Systems* 83-128, cambridge university Press, London.

Jarvis, P.G. 1971: The estimation of resistances to carbon dioxide transfer, In: (sestak, Z., Catsky, J. and Jarvis, P.G. eds.) *Plant Photosynthetic Production mannual of Methods* 566-631, Junk, The Hague.

Jarvis, P.G., James, G.B. and Landsberg, J.J. 1976: Coniferous forests. In: (Monteith, L.L. ed.) *Vegetation and the Atmosphere*, Academic Press , New York and London.

Jha, M. N., Dimri, B. M. and Gupta, M. K. 1991 : Soil nutrient changes in *Leucaena leucocephala* planting of different durations. *Leucaena Research Reports* 12: 42 - 44.

Johnson, C.B., Whittington, W.J. and Blackwood, G.C. 1976: Nitrate reductase as a possible predictive test of crop yield. *Nature* 262: 133-134.

Johnson, F.L. and Risser, P.G. 1974: Biomass, annual net primary production and dynamics of six mineral elements in a post oak black jack oak - forest. *Ecology* 55: 1246 - 1258.

Johnson, I. R. and Thornley, J. H. M. 1987 : A model of shoot : root partitioning with optimal growth. *Annals of Botany* 60: 133 - 212.

Jolliffe, P.A. and Tregunna, E.B. 1969: Estimation of CO2 free exchange pool size in wheat and corn leaves. *Can. J. Bot.* 47(9): 1506-1508.

Jones, P.W. and Whittington, W.J. 1982: Seasonal fluctuations of nitrate reductase activity in ditelosomic stocks of wheat. *J. Experimental Bot.* 33(134): 477-486.

Jordan, C.F. 1983: Productivity of tropical rain forest ecosystems and the implications for their use as future wood and energy sources, In: (Golley, F.B. ed.) *Tropical rain Forest Ecosystems, Structure and Function,* Elsevier, Amsterdam.

Jorden, P.W. and Nobel, P.S. 1984: Thermal and water relations of roots of desert succulents. *Ann. Bot.* 54: 705 - 717.

Jose, M. and Gomez . 1993: Phenotypic selection on flowering synchrony in a high mountain plant *Hormanthophylla spinosa. J. Ecol.* 81: 605 - 613.

Joshi, S.K., Pati, D.P. and Behera, N. 1990: Primary production of herbaceous layer in a tropical deciduous forest in Orissa, India. *Trop. Ecol.* 31(2): 73-83.

Joshi, U. N., Arora, S. K. and Paroda, R. S. 1986 : Profile of mimosine during growth of *Leucaena leucocephala. Leucaena Research Reports* 7: 51 - 52.

Jung, G.A. and Larson, K.L. 1972: Cold, Drough and Heat Tolerance 9: *Alfalfa Science and Technology,* Amer. Soc. Agron. Monograph 15:185.

Kaiser, W.M. 1987: *Current Topics in Plant Biochemistry and Physiology.* 6: 119 - 133.

Kakati, L.N. and Yadava, P.S. 1990: Seasonal changes in chlorophyll and carotenoides content in a grassland ecosystem at Imphal. *Trop. Ecol.* 31(1): 82 - 88.

Kaul, R. 1974: Study of the seasonal variation of the water content of the leaves and the rate of transpiration in *Hemigraphis dura. J. Indian Bot. Soc.* 53: 97 - 99.

Kaufman, J.E., J. B. Beard and fenner, D. 1971: Influence of temperature on nitrate reductase activity of *Agrostis palustris* and *Cynodon dactylon. Plant Physio*l. 25: 378 -381.

Kehar, N. D. and Goswami, M. N. D. 1956 : Nutritive value of feeds - tree leaves and shrubs. In : *Research in Animal Husbandry - A Review* 1929 54, p 77. ICAR, New Delhi.
(1962)

Khan, T. A. and Pathak, P. S. 1986 : Biomass prediction models in *Leucaena leucocephala* (Lam.) de wit. plantations. *Leucaena Research Reports* 7: 53 - 54.

Khan, T. A. and Pathak, P. S. 1989 : Biomass prediction in *Leucaena leucocephala* grown on wetlands. *Leucaena Research Reports* 10 : 27 - 28.

Khan,T. A., Pathak, P. S. and Gupta, S. K. 1993: Statistical analysis of growth and biomass production data in some multipurpose trees. *Indian Forester* 119 (5): 371 - 374

Khan,T.A., Pathak, P. S. and Gupta, S. K. 1993: Size and shape of a plot/block for *Acacia tortilis* based silvipastoral system, *Range Mgmt. & Agroforestry* 14(1): 85-91.

Khan,T.A. and Pathak, P. S. 1993: Allometric relationships in *Leucaena leucocephala .Range Mgmt. & Agroforestry,* 14(2) : 207 - 218.

Khan, T.A., Pathak, P. S., Deb Roy, R. and Gupta, S. K.. 1993: Prediction models for volume of timber and total wood biomass in *Hardwickia binata* grown under silvipastoral system. *J. Tree Sci.* 12(2): 73 - 76.

Khan, T. A. and Pathak, P. S. 1994. Biomass prediction in *Leucaena leucocephala, Indian Forester* 120 (6): 533 - 537.

Khan,T.A., Pathak, P. S. and Gupta, S. K. 1994: Modelling *Acacia tortilis* based silvipastoral system using systems analysis methodologies. *Range Mgmt & Agroforestry* 15(2) : 203 - 210.

Khan, T.A., Pathak, P. S. and Gupta, S. K. 1995. Statistical analysis of growth and biomass production data in some multipurpose trees. *J. Tree Sci.* 14(1): 33 - 36.

Khan, T.A. and Pathak, P. S. 1996: Biomass prediction in *Leucaena leucocephala, J. Tree Sci.* 15(1): 18 - 21.

Khiewatam, R. S. and Ramakrishnan, P. S. 1993: Litter and fine root dynamics of a relic sacred grove forest at Cherrapunji in north eastern India. *Forest Ecology and Management* 60: 327 - 344.

Khot, R. B., Desale, J. S. and Patil, S. K. 1991 : Effect of spacing and harvest duration on fuel yield of *Leucaena* regrowth. *Leucaena Research Reports* 12: 47.

Kikuzawa, K. 1983: Leaf survival of woody plant in deciduous broad leaved forests. 1. Tall trees. *Canadian J. Botany* 61: 2133 - 2139.

Kimura, M., Funakoshi, M., Sudo, S., Kimura, W., yamamura, Y., Honma, S. 1984 : Litter fall and reproductive seasonalities in a *Leucaena leucocephala* forest at Chichifima, Ogasawara (Bonin) Islands, *Bot. Mag. (Tokyo)*, 97 (1048): 447 - 455.

Kira, T. and Shidei, T. 1967: Primary production and turn over of organic matter in different forest ecosystems of the western Pacific. *Japanese J. Ecology* 17: 70 - 87.

Kleeper, B., Browning, V. D. and Taylor, H. M. 1971 : Stem diameter in relation to plant water status. *Pl. Physiol. Lancaster*. 48: 683 - 5.

Kohyama, T. 1980: Maize leaf elongation continuous measurement and close depend device on plant water status. *Bot. Mag. Tokyo* 33: 13 - 24.

Koelmeyer, K. O. 1959: The periodicity of leaf change and flowering in the principal forest communities of Ceylon. *Ceylon Forester* 4: 308 - 364.

Koriba, K. 1958: On the periodicity of tree growth in the tropics with reference to the mode of branching, the leaf fall and the formation of resting bud. *Gard. Bull. Singapore* 17: 11 - 81.

Kozlowski, T.T. 1964: Shoot growth in woody plants. *Bot. Rev.* 30: 335 - 392.

Kozlowski, T.T. 1971: *Growth and Development of Trees. Vol. II. Cambial Growth, Root Growth and Reproductive Growth.* Academic Press, New York.

Kozlowski, T. T. and Claussen, J. J. 1966 : Shoot growth characteristics of heterophyllous woody plants. *Can. J. Bot.* 44: 827 - 843.

Kramer, P.J. 1943: Amount and duration of shoot growth in tree seedlings. *Pl. Physiol.* 19: 239 - 257.

Kramer, P. J. and Clark, W.S. 1947: A comparison of photosynthesis in individual pine needle and entire seedlings at various light intensities. *Pl. Physiol.* 22: 51 - 57.

Kramer, P.J. and Kozlowski, T.T. 1960: *Physiology of Woody Plants*, Academic Press, New York.

Kramer, P.J. and Kozlowski, T.T. 1979: *Physiology of Woody Plants,* Academic Press, New York.

Krishnamurthy, K. and Munegowda, M. K. 1983 : Forage yield of *Leucaena* variety K 8 under rainfed conditions. *Leucaena Research Reports* 4: 25 - 26.

Krishnamurthy, K. and Munegowda, M. K. 1983 : Mimosine concentration in *Leucaena* cultivars. *Leucaena Research reports* 4: 27 - 28.

Ku, S.B., Edward, G.E. and Tanner, C.B. 1977: Effect of light, carbon dioxide and temperature on photosynthesis, oxygen inhibition of photosynthesis and transpiration in *Solanum tuberosum. Plant Physiol.* 59: 868 - 872.

Kumar, A. and Joshi, M.C. 1980: Grazing and site differences affect, energy storage and energy conserving efficiency in grassland communities at Pilani, Rajasthan, India. *Trop. Ecol.* 21(1&2): 1 - 8.

Kunkel - Westphal, I. and Kunkel, P. 1979: Litter fall in Guatemalan primary forest with details of leaf shedding by some common tree species. *J. Ecol.* 67: 665 - 686.

Lakshmanachary, A.S. 1987: Energy values and efficiency of net primary production of *Cynodon - Urochloa* grassland of south Arcot district. In (Ambasht, R. S. ed.): *IX International Symposium on Tropical Ecology and international conference on rehabilitation of disturbed ecosystems*, Dec. 11-16, 108 pp.

Lal, Girdhari 1988 : Soil nitrogen accumulation under *Leucaena leucocephala. Leucaena Research Reports* 9: 49.

Lamotte, M. and Bourliere, F. 1983: Energy flow and nutrient cycling in tropical savannas. In (Bourliere, F. ed.) : *Ecosystems of the World : Tropical Savannas* 13: 583 - 603.

Lange, O. L., Koch, W. and Schulze, E.D. 1969: CO2 Gaswechsel und Wasserhaushatt von Pflanzen in der Negevwieste an Ende der Trockenzeit Ber. Deutsch. *Bot. Ges.* 82: 39 - 61.

Lawlor, D.W. 1970: Absorption of poly-ethylene glycol by plants and their effect on plant growth. *New Phytol.* 69: 501.

Ledig, F.T. and Perry, T.O. 1967: Variation in photosynthesis and respiration among loblolly pine progenies. In : *Proceedings of the Ninth Southern Conference on Forest Tree Improvement*, 120 - 128, Knowville, Tennessee.

Ledig, F.T. 1969: A growth model for tree of seedlings based on the rate of photosynthesis and the distribution of photosynthate. *Photosynthetica* 3: 263 - 275.

Ledig, F.T., Borman, F.H. and Wenger, K.F. 1970: The distribution of dry matter growth between shoot and roots in loblolly pine. *Bot. Gaz.* 131: 349 - 359.

Ledig, F.T. 1974: Concept of growth analysis. In (Reid, C.P.P. and Fechner, G.H. eds.): *Proceedings of the Third North American Forest Biology Workshop*, 166 - 182, Colorado State University, Fort Collins, Colorado.

Ledig, F.T. and Botkin, D.B. 1974: Photosynthetic CO_2 uptake and the distribution of photosynthate as

related to growth of Larch hemlock seedlings. *Can. J. Bot.* 47: 519 - 527.

Ledig, F.T., Drew, A.P. and Clark, J.G. 1976: Maintenance and constructive respiration, photosynthesis and net assimilation rate in seedlings of Pitch Pine (*Pinus rigida* Mill.), *Ann. Bot.* 40: 289 - 300.

Lee, K.E. and Wood, T.G. 1971: *Termites and Soils,* Academic Press, London, 251 p.

Legg, B.J., Day, W., Lawlor, D.W. and Parkinson, K.J. 1979: The effects of drought on barley growth: models and measurements showing the relative importance of leaf area and photosynthetic rate, *J. Agricultural Sci*(Cambridge) 92: 702 - 716.

Lieth,H. 1962: *Die Stoffproduction der Pflanzendecke Stuttgart,* Fischer Verlag, 156pp.

Lieth, H. 1970: Phenology in productivity studies: Analysis of temperate forest ecosystems, In (Reichie, D.E. ed.) *Ecological Studies*, Vol. I : 29 - 46, Springer - Verlag.

Lieth, H. 1971: The phenological view point in productivity studies, *Productivity of Forest Ecosystems,* Proc. Bruss. Symp. UNESCO, 71 - 84.

Lieth, H. and Radford, J.S. 1971: Phenology, resource management and synagraphic computer mapping, *Bioscience* 21: 62 - 70.

Lindeman, R.L. 1942: The Trophic Dynamic Aspect of Ecology, *Ecology* 23: 399 - 418.

Lodhiyal, L.S., Singh, R.P. and Rana, B.S. 1992: Biomass and productivity in an age series of short rotation *Populus deltoides* plantations, *Tropical Ecology* 33(2): 214 - 222.

Longman, K.A. 1966: Effect of the length of the day on growth of west African trees, *J.W. Afr. Sci. Assoc.* 11: 3 - 10.

*Longman, K.A. and Jenik, J. 1974: *Tropical Forests and its Environment*, Longman Group.

Loomis, A.S., William, W.A. and Hall, A.E. 1971: Agricultural productivity, *Ann. Rev. Pl. Physiol.* 22: 431 - 468.

Louwerse, W. and Van der Zweerde, W. 1977: Photosynthesis, transpiration and leaf morphology of *Phaseolous vulgaris* and *Zea mays*, *Photosynthetica* 11: 11.

Ludlow, M.M. 1987: Light stress at high temperature, In (Kyle, D.J., Osmond, C.B. and Arntzen, C.J. eds.): *Photoinhibition - Topics in Photosynthesis*, 9: 89 - 110, Elsevier, Amsterdam.

Lulandala, Luther L. L. 1981 : Seed viability, germination and pretreatment of *Leucaena leucocephala. Leucaena Research Reports* 2: 59 - 61.

Macfaydyen, A. 1963: Metabolism of soil invertebrates in relation to soil fertility. *Ann. appl. Biol.* 49: 215 - 218.

Madge, D. S. 1969: Litter disappearance in forest and savanna. *Pedobiologia* 9: 288 - 299.

Majumdar, B. N. 1967 : Studies on the tree leaves as cattle fodder I. Chemical composition as affected

by the stage of growth. *Indian J. Vet. Sci.* 37 : 217 - 223.

Majumdar, B. N., Momin, S. A. and Kehar, N. D. 1967 : Studies on tree leaves as cattle fodder I. Chemical composition as affected by stage of growth. *J. Vet. Sci.* 37: 217 - 223.

Mall, L. P., Billore, S. K. and Misra, C, M. 1973 : A study on the community chlorophyll content with reference to height and dry weight. *Trop. Ecol.* 14: 81 - 83.

Mandal, S. C. 1989 : Soil research in retrospect and prospect - acid soils of India. In : *Soil Science in India.* Bull. No. 14. *Indian Soc. Soil Sci.*, New Delhi pp 158 - 168.

Mani, Anna and Rangrajan, S. 1982 : *Solar Radiation Over India*, DST, Govt. of India, Allied Publishers, New Delhi, pp. 646.

May, D. E. and Webber, P. J. 1982: Spatial and temporal variation of the vegetation and its productivity, Niwot ridge, Colorado, In (Haipenny, J.C. ed.): *Ecological Studies in the Colorado Alpine University of Colorado* 35-62, Institute of Arctic and Alpine Research, Occasional Paper.

Mc Cree, K. J. and Troughton, J. H. 1966: Non - existence of an optimum leaf area index for the production rate of white clover grown under constant conditions, *Pl. Physiol.* 41: 1615.

Mc Cree, K. J. 1972: The action spectrum, absorptance and quantum yield of photosynthesis in crop plants, *Agricultural Meteorology* 9: 191 - 216.

Medway, L. 1972: Phenology of a tropical rain forest in malaya, *Biological Journal of Linnean Society* 4: 117 -147.

Mebrahtu, Tesfai and Hanover, J. W. 1991: Effects of nitrogen level on photosynthesis, growth and leaf traits of black locust. *Nitrogen Fixing Tree Res. Rep.* 9: 130 - 133.

Menaut, J. C. 1983: The vegetation of Africal savannas, In (Bourliere, F. ed.): *Tropical Savanna Ecosystem in South Eastern Botswana,* 293 pp., Free Iniv., Amsterdam.

Mendoza, R. C., Altamarino, T. P. and Javier, E. O. 1983 : Herbage, crude protein and digestible dry matter yield of Ipil - Ipil (*Leucaena leucocephala* cv Peru) in hedge rows. *Leucaena Research Reports* 4: 69.

Milthrope, F. L. 1959: Studies on the expansion of leaf surface. I. The influence of temperature, *J. Exp. Bot.* 10: 233 - 249.

Miguel, G. G. 1981: The assimilatory nitrate reducing system and its regulation, *Ann. Rev. Pl. Physiol.* 32: 169 - 204.

Misra, R., Singh, J. S. and Singh, K. P. 1967: Preliminary observations on the production of dry matter by sal (*Shorea robusta* Gaertn.), *Trop. Ecol.* 8: 94 - 104.

Misra, M. K. and Misra, B. N. 1981: Seasonal changes in leaf area index and chlorophyll in an Indian grassland, *J. Ecol.* 69: 797 - 805.

Mooney, H. A. and Billings, W. D. 1961: Comparative physiological ecology of arctic and alpine populations of *Oxyria digyna*, *Ecol. Monogr.* 31: 1 - 29.

Mooney, H. A., Wright, R. D. and Strain, B. R. 1964: The gas exchange capacity of plants in relation to vegetation zonation in the white mountains of California. *Am. Midl. Nat.* 72: 281.

Mooney, H. A. and West, M. 1964: Photosynthetic acclimation of plants of diverse origin. *Am. J. Bot.* 51: 825.

Mooney, H. A., Strain, B. R. and West, M. 1966: Photosynthetic efficiency at reduced carbon oxide tension. *Ecology* 47: 490 - 491.

Mooney, H. A., Bjorkman, O. and Collatz, G. J. 1977: Photosynthetic acclimation to temperature and water stress in the desert shrub, *Larrea divaricata. Carnegie Institution Year Book* 76: 325 - 335.

Mohamed, H. A., Clarke, J. A. and Ong, C. K. 1988: Genotypic differences in the temperature responses of tropical crops. III. Light interception and dry matter production of pearl millet (*Pennisetum typhoides* S. & H.*), J. Experimental Botany* 39: 800 - 830.

Monsi, M., Uchijima, Z. and Oikawa, T. 1973: Structure of foliage canopies and photosynthesis, *Ann. Rev. Ecol. Syst.* 4: 301 - 327.

Monteith, J. L. 1965: Light distribution and photosynthesis in field crops, *Annals of Botany*, N.S. 29: 17 - 37.

Muthuchelian, K., Paliwal, K. and Gnanam, A. 1986: Physiological studies of two fast growing tree species in semi - arid ecoclimate at Madurai. *Indian Forester* 112(9): 814 - 818.

Naidu, C.V. and Swamy, P. M. 1993: Effect of shade on growth, biomass production and associated physiological parameters in *Pongamia pinnata* (Linn.) Pierre. *Indian J. Plant Physiology* 34(4): 212 - 214.

Naidu, C.V. and Swamy, P. M. 1996 : Seasonal patterns of carotenoids and chlorophyll content in some selected tropical deciduous tree species under natural conditions. *Ann. For.* 4(1): 89 - 93.

Naidu, C. V. and Swamy, P. M. 1996 : Relationship between leaf starch content and net photosynthetic rate in tropical deciduous tree species. *Ann. For.* 4(1): 111 - 112.

*Nanda, K. K. and Purohit, A. N. 1966: *Indian J. Plant Physiology* 9: 42 - 51.

Natrahan, K., Paliwal, K. and Gnanam, A. 1985: Diurnal course of CO2 exchange in *Leucaena leucocephala* var. K8 in the semi - arid climate of Madurai, *Leucaena Research Reports* 6: 41 - 42.

National Academy of Sciences 1977 : *Leucaena ; Promising Forage and Tree Crop for the Tropics.* Washington D.C.

N. A. S. 1984: *Leucaena : Promising Forage and Tree Crop for the Tropics.* II nd edition, National Academy of Sciences, Washington D.C.

N. C. A. 1976 : Forestry Development. national Commission on Agriculture, Govt. of India, Ministry of Agriculture, New Delhi.

N. R. C. 1984 : *Leucaena : Promising Forage and Tree Crop for the Tropics.* II nd edition, National

Academy of Sciences, Washington D.C.

Nasyrov, Yu. S. 1981: Genetic modification of the CO_2 carboxylation reaction as a factor improving efficiency of photosynthesis, *Indian J. Plant Physiology* 24(1): 16 - 36.

Neals, T.F., Patterson, A.A. and Hastney, V.J. 1968: Physiological adaptation to drought in the carbon assimilation and water loss of xerophytes, *Nature* 219: 469.

Ne'eman, G. 1993: Variation in leaf phenology and habit in *Quercus itha burensis* a mediterranean deciduous tree, *J. Ecology* 81: 627 - 634.

Negi, K. S., Rawat, Y. S. and Singh, J. S. 1983: Estimation of biomass and nutrient storage in a Himalayan moist temperate forest, *Canadian J. Forest Research* 13: 1185 - 1196.

Njoku, E. 1963: Seasonal periodicity in the growth and development of some forest trees in Nigeria. I. Observations on mature trees, *J. Ecology* 51: 617 - 624.

Njoku, E. 1964: Seasonal periodicity in the growth and development of some forest trees in Nigeria. II. Observations on seedlings, *J. Ecology* 52: 19 - 26.

Nobel, P. S. 1977: Water relations and photosynthesis of a barrel cactus, *Ferocactus acanthodes* in Colorado desert, *Oecologia* 27: 117.

Nunes, M. A., Ramalho, J. D. C. and Rijo, P. D. 1992: Seasonal changes in some photosynthetic properties of *Cerotonia siliqua* (Carob tree) leaves under natural condition, *Physiol. Plantarum* 86: 381 - 387.

Odum, H. T. 1956: Efficiencies, size of organisms and community structure, *Ecology* 37: 592 - 597.

Ola- Adams, B. A. and Egunjobi, J. K. 1992: Effects of spacing on litter fall and nutrient contents in stands of *Tectona grandis* Linn.f. and *Terminalia superba* Engl. and Diels. *African Journal of Ecology* 30: 18 - 32.

Oldeman, R. A. A. 1974: L'architecture de la for'et guyanaise, *Mem ORSTOM,* 73.

Onweune, T. C., Laude, H. M. and Huffaker, R. C. 1971: Nitrate reductase activity in relation to heat stress in Barley seedlings, *Crop Science* 11: 195 - 200.

Opler, P. A., Frankie, G. W. and Baker, H.G. 1976: Rainfall as a factor in the release, timing and synchronisation of anthesis by tropical trees and shrubs, *Journal of Biogeography* 3: 231 - 236.

Osman, Azad M. 1981 : Effect of cutting interval on the relative dry matter production of four cultivars of *Leucaena. Leucaena Research Reports* 2: 33 - 34.

Ovington, J. D. 1960: The ecosystem concept as an aid to forest classification, *Tropical Ecology* 1(2): 54 - 57.

Ovington, J. D. 1962: Quantitative ecology and the woodland ecosystem concept, *Adv. Ecol. Res.* 1: 103 - 192.

Ovington, J. D., Heitkamp, D. and Lawrence, D. B. 1963: Plant biomass and productivity of prairie,

savannah, oakwood and maize field ecosystems in central Minnesota, *Ecology* 45: 52 - 63.

Ovington, J. D. 1965: Organic production, turn over and mineral cycling in woodlands, *Biological Review* 40: 295 - 336.

Ovington, J. D. and Lawrence 1967: Comparative chlorophyll and energy studies of prairie, savannah, oakwood and maize field ecosystem, *Ecology* 48: 515 - 524.

Pal, R. N., Dogra, K. K., Singh, L. N. and Negi, S. S. 1979 : Chemical composition of some fodder trees in Himachal Pradesh. *Forage Research* 5: 109 - 115.

Palta, J. A. 1983: Photosynthesis, transpiration and leaf diffusive conductance of cassanava leaf in response to water stress. *Canadian J. Botany* 61: 373 - 376.

Paliwal, K. and Muthuchelian, K. 1988: Ecophysiological studies of *Cenchrus ciliaris* L. : Growth, productivity, photosynthesis and nitrate assimilation. *Internantional J. Ecology and Environmental Sciences* 14: 167 - 174.

Pandey, B. N. and Sinha, R. P. 1977: Light as a factor in growth and morphogenesis. I. Effect of artificial shading on *Crotalaria juncea L.* and *C. sericea* Retz. *New Phytol*. 79: 431.

Pandey, T. N. 1977: Measurement of rate of primary production in Varanasi grassland. Ph. D. thesis, Banaras Hindu University, Varanasi, India.

Pandey, D. D. and Sant, H. R. . 1979: Energy flow into primary producers of protected and grazed grassland ecosystem at Varanasi, India. *Geo-Eco-Trop*. 3(3): 185 - 192.

Pandey, Uma and Singh, J. S. 1981: A quantitative study of the forest floor, litter fall and nutrient return in an oak - conifer forest in Himalaya. *Acta Oecologia, Oecologia Generalis* 2(2): 83 - 99.

Pandeya, S. C., S. C. Sharma and R. R. Pandit. 1970: Dry matter production relations of Sal (*Shorea robusta* Gaertn.) in the reserve forest communities in river Narmada upper catchment area. *J. Indian Bot. Soc.* 50(A): 601 - 660.

Pandeya, S. C., Pandit, R. R. and Sharma, S. C. 1972: Biomass and production relations of teak (*Tectona grandis* Lin. f.) in natural reserve forests in central India. In (Golley, P. M. and Golley, F. B. eds.): *Tropical Ecology with an emphasis on organic production*, 201 - 216, University of Georgia, Athens.

Panse, V. G. and Sukhatme, P. V. 1967 : *Statistical Methods for Agricultural Workers*, Second ICAR Publication.

Pant, S. C. and Tiwari, S. C. 1992: Litter fall and litter decomposition in a montane oak forest of Garhwal Himalaya. *Trop. Ecol.* 33(1): 103 - 109.

Paroda, R. S. 1975: Leafiness - an important criterion for improvement in yield and quality of forages. *Forage Research* 1: 149.

Paroda, R. S. 1996 : Indian Agriculture - emerging trends and future strategies : 36 - 47. *Souvenir 2nd International Crop Science Congress,* November 17 - 24, 1996, New Delhi, India.

Pate, J. S. 1980: Transport and partitioning of nitrogenous solutes. *Ann. Rev. Plant Physiol.* 31: 313 - 340.

Pathak, P. S. and Gupta, S. K. 1987 : Productivity of *Leucaena leucocephala* (lam.) de wit. on moist wastelands. *J. Tree Sci.* 6(2): 50 55.

Pathak, P. S. and Gupta, S. K. 1991 : Growth and biomass production characteristics of minirotations species on marginal lands. *International J. Ecol. Environ. Sci* 17: 139 - 148.

Pathak, P. S. and Gupta, V. K. 1994 : Evaluation of some new selections of *Leucaena leococephala* on dry degraded lands. In (Singh, P., Pathak, P. S. and Roy, M. M. eds.) *Agroforestry Systems for Degraded Lands* 1: 302 - 307. Oxford & IBH Publ. Co. Ltd. , New Delhi.

Pathak, P. S. and Naugraiya, M. N. 1992 : Germination, growth and dry matter allocation in *Leucaena* species in different seasons. *International J. Ecology and Env, Sci.* 18: 79 - 84.

Pathak, P. S., Deb Roy, R. and Rai, P. 1974: Autecology of *Leucaena leucocephala* (lam.) De wit. I. Seed polymorphism and germination. *Trop. Ecol.* 15: 1-10.

Pathak, P. S., Gupta , S. K. and Deb Roy, R. 1984: Productivity of *Leucaena leucocephala* (Lam.) de wit on moist wastelands. *J. Tree Scci.* 3(1 - 2): 15 - 19.

Pathak, P. S., Gupta , S. K. and Deb Roy, R. 1984: Autecology of *Leucaena leucocephala* (Lam.) de Wit. III. Meteroglyph analysis of seedling characteristics. *J. Tree Sci.* 3(102) : 15 - 19.

Pathak, P. S., Gupta, S. K. and Deb Roy, R. 1985 : Biomass accumulation pattern and the productivity of *Leucaena* minirotation on moist wastelands. *J. Trop. Forestry* 1(ii): 112 - 123

Pathak, P. S. and Patil, B. D. 1981 : Production performance of Kubabool (*Leucaena leucocephala (Lam.)* de wit. with special reference to its giant varieties. *Proc. National Seminar on Subabul*, Uruli Kanchan.

Pathak, P. S., Rai, P. and DebRoy, R. 1980 : Forage production from *Koo - babool* (*Leucaena leucocephala* (Lam.) de Wit.) I. Effect of plant density, cullting intensity and interval. Forage Research 6: 83 - 90.

Patil, B. D. and Pathak, P. S. 1977 : Energy plantation and silvipastoral systems for rural areas. *Invention Intelligence* 12(1&2): 79 - 87.

Pecson, Richard D. and Brewbaker, James L. 1991 : Coppice shoot regrowth of *Leucaena. Leucaena Research Reports* 12: 119 - 120.

Peet, M. M., Ozbun, J. L. and Wallace, D. H. 1977: Physiological and anatomical effects of growth temperature on *Phaseolus vulgaris*. L. cultivars. *J. Exp. Bot.* 28(102): 57.

Paterken, G. F. and Newbould, P. J. 1966: Dry matter production by *Ilex aquifolium* in the new forest. *J. Ecol.* 54: 143 - 150.

Phillipson, J. 1966: *Ecological Energetics*. Edward Arnold Pub. Ltd., London.

Pisek, A., Larcher, W., Moser, W. and Pack, I. 1969: Kardinale temperaturebereiche und grenztemperaturen des lebens der Blatter verschiendener spermatophyten. III. Temperat abhangig

Keit und optimaler temperaturbereichder Netto - photosynthese. *Flora (Jena)*, Abt. B. 158: 608 - 30.

Pizelle, G. and Thiery, G. 1986: Reduction of nitrate in the perennial tissues of aerial parts of *Alnus glutinosa*, *Physiol. Plantarum* 68: 347 - 352.

Pokhriyal, T. C., Raturi, A. S., Pant, S. P. and Joshi, S. R. 1989: Physiological studies on the leaves of *Populus deltoides* in relation to nitrate assimilation. *Indian J. Pl. Physiol.* XXXVII (1): 80 - 82.

Pokhriyal, T. C., Negi, D. S., Chaukiyal, S. P., Bhandari, H. C. S. and Gupta, B. B. 1990: Changes in nitrogenase and nitrate reductase activity in *Acacia catechu*. *Nitrogen Fixing Tree Research Reports* 8: 108 - 110.

Porter, J. R. 1983: A modular approach to analysis of plant growth. I. theory and principles. *New Phytol.* 94: 182 - 90.

Porter, J. R. 1989: Modules, models and meristems in plant architecture. In (Russel, Marshall and Jarvis eds.): *Plant Canopies : their Growth Form and Function*, 143 - 160, Cambridge Univ. Press.

Potter, J. R. 1980 : Maintenance of high photosynthetic rates during the accumulation of high leaf starch levels in sun flower and soyabean. *Plant Physiol.* 66: 528 - 531.

Prasad, M. N. V. and Rajeswar, J. 1989: Carbon dioxide assimilation in leaves and developing pods of *Leucaena leucocephala* with remarks on its productivity and phytomass composition. *Leucaena Research reports* 10: 35 - 39.

*Purohit, A. N. and Nanda, K. K. 1968: *Canadian J. Bot.* 46: 1287 - 1295.

*Purohit, A. N. and Dhyani, P. P. 1988: *Acta Biotheoretica* 37: 3 - 26.

Purohit, A. N. 1994: Ecophysiology of fast and slow growing trees and some emerging trends. *J. tree Sci.* 13(1): 1 - 12.

Putz, F. E. 1979: A seasonality in Malasian tree phenology. *Malasian Forester* 42: 1 - 24.

Rabinowitch, E. I. 1951: *Photosynthesis and Related Processes.* vol II. part 1, New York, Wiley Inter Science.

Radin, J. W. and Ackerson, R. C. 1981: Water relations of cotton plants under nitrogen deficiency. III. Stomatal conductance, photosynthesis and abscisic acid accumulation during drought. *Plant Physiology* 67: 115 - 119.

Radin, J. W. and Boyer, J. S. 1982: Control of leaf expansion by nitrogen nutrition in sun flower plants : role of hydraulic conductivity and turgor. *Plant Physiology* 69: 771 - 775.

Rai, S. N. 1981: *Productivity of tropical rain forests of Karnataka.* Ph. D. thesis, Bhavan's College, Bombay.

Rai, M. P., Pathak, P. S. and Deb Roy, R. 1983: Biomass production of *Sesbania grandiflora* Pers. in different habitats. *Int. J. Ecol. Environ. Sci.* 9: 21 - 27.

Raizada, A. and Srivastava, M. M. 1989: Biomass yield and biomass equations for *Populus deltoides* March. *Indian J. of Forestry* 12(1): 56 - 61.

Rajvanshi, R. and Gupta, S. R. 1980: Decomposition of litter in a tropical dry deciduous forest. *Int. J. Ecol. Environ. Sci.* 6: 37 - 49.

Rajvanshi, R. and Gupta, S. R. 1985: Mineral cycling in a tropical deciduous *Dalbergia sissoo* Roxb. forest. *Acta Oecologia. Oecol. Plant.* 6: 247 - 262.

Ralhan, P. K., Khanna, R. K., Singh, S. P. and Singh, J. S. 1985 a: Phenological characteristics of the tree layer of Kumaun Himalayan forests. *Vegetatio* 60: 91 - 101.

Ralhan, P. K., Khanna, R. K., Singh, S. P. and Singh, J. S. 1985 b: Certain phenological characters of the shrub layer of Kumaun Himalayan forests. *Vegetatio* 63: 113 - 120.

Ramakrishnan, P. S. 1978: Observations on biological aspects of productivity of forest ecosystems, In (Singh, J. S. and Gopal, B. eds.) *Glimpses of Ecology* 194 - 199, International Scientific Publications.

Ramakrishnan, P. S. and Das, A. K. 1983: Studies of pine ecosystems in Meghalaya. *Tropical Plant Science Research* 1(1): 15 - 24.

Rana, B. S., Singh, S. P. and Singh, R. P. 1988: Biomass and productivity of central Himalayan Sal (*Shorea robusta*) forest. *Trop. Ecol.* 29(2): 1 - 7.

Rana, B. S., Singh, R. P. and Singh, S. P. 1989: Carbon and energy dynamics of seven central Himalayan forests. *Trop. Ecol.* 30(2): 253 - 264.

Randel, P. W. and Nobel, P. S. 1991: Structure and function in desert root systems. In (Atkinson, D. ed.) *Plant Root Growth - an Ecological Perspective* 349 - 378.

Randhawa, M. S. 1956: *Flowering Trees of India,* ICAR, New Delhi.

Rao, G. G. S. N., Raman, B. V. and Bhati, G. N. 1984: Influence of water availability on water and energy use efficiencies of some arid grass species. *Trop. Ecol.* 25(1): 117 - 124.

*Raper, C. D. (Jr.), Johnson, W. N. and Downes, R. J. 1971: *Agron. J.* 63: 283.

Ratchke, B. and Lacey, E. P. 1985: Phenological pattern of terrestrial plants. *Ann. Rev. Ecol. & Systematics* 16: 179 - 214.

Rawat, Y. S. 1983: Plant biomass, net primary production and nutrient cycling in oak forests. Ph. D. thesis, Kumaon University, Nainital, India.

Rawat, Y. S. and Singh, J. S. 1988 a: Structure and function of Oak forests in central Himalaya. I. Dry matter dynamics. *Annals of Botany* 62: 397 - 411.

Rawat, Y. S. and Singh, J. S. 1988 b: Structure and function of oak forests in Central Himalaya. II. Nutrient dynamics. *Annals of Botany* 62: 413 - 427.

Redman, R. E. 1975: Production ecology of grassland plant communities in Western North Dakota. *Ecol*

Monogr. 45: 83 - 106.

Relwani, L. L. and Khandale, D. Y. 1988 : *Leucaena* (*Leucaena leucocephala* (Lam.) de wit) a potential fodder tree for livestock. In (Singh, Panjab ed.) *Pasture and Forage Crops Research*, 342 - 353, R. M. S. I., Jhansi.

Relwani, L. L., Deshmukh, S. S., khandale, D. Y. and Nakat, R. V. 1982 : Growth rates of *Leucaena* under different systems of tree management. *Leucaena Research Reports* 3: 38.

Richards, P. W. 1952: *The Tropical Rain Forest : An Ecological Study*, Cambridge University Press, London.

Romberger, J. A. 1963: *Meristems growth and development in woody plants.* USDA Forest Service Tech. Bull. 1293.

Ross, J. 1981: *The Radiation Regime and Architecture of Plant Stands.* The Hague : W. Junk.

Rutter, A. J. 1968: Water consumption by forests. In (Kozlowski, T. T. ed.) *Water Deficit and Plant Growth,* 23 - 64, Academic Press, London.

Rutter, A. J. and Whitehead, F. H. 1963: *The Water relations of Plants.* Blackwell, Oxford.

Russel, G., Jarvis, P. G. and Monteith, J. L. 1989: Absorption and radiation by canopies and stand growth. In (Russel, G., Marshall, B. and Jarvis, P. G. eds.) *Plant Canopies : Their Growth Form and Function,* 21 - 40, Cambridge University Press.

Sah, V. K., Saxena, A. K. and Singh, Virendra. 1994: Seasonal variation in plant biomass and net primary productivity of grazing lands in the forest zone of Garhwal Himalaya. *Trop. Ecol.* 35(1): 115 - 132.

Sanchez - Alvarez, Javier and Guevara Sada, Sergio. 1993: Litter fall dynamics in a Maxican low land tropical rain forest. *Trop. Ecol.* 34 (2): 127 - 142.

Sanchez - Alvarez, Javier and Guevara Sada, Sergio. 1995: Litter fall in tropical forests of Mexico. *Trop. Ecol.* 36 (2): 191 - 201.

Schulze, E. D., Lange, O. L. and Koch, W. 1972: Okophysiologische untersuchungen an wildund kulturpflangen der Neger - wiiste. II. Die Wirkung der Aubenfaktoren auf CO2 Gaswechsel und Transpiration an Ende der trockenzeit. *Oecologia* (Berl.) 8: 334 - 355.

Scott, D. and Menalda, P.H. 1972: CO_2 exchange of plants. 2. response of 6 species to temperature and light intensity. *N. Z. J. Bot.* 8: 361 - 368.

Seghieri, J. 1990: Dynamique saisonniere d'une savane soudano - sahelienne au nord - cameroun. These, Acad. Montpellier, University Montpellier II. 200pp.

Sen, K. C., Ray, S. N. and Ranjhan, S. K. 1978 : *Nutritive Value of Indian Cattle Feeds and Feeding of Animals,* Indian Council of Agricultural Research, New Delhi.

Sestak, Z. 1981 : Leaf ontogeny and photosynthesis. In (Johnson, C. B. ed.) *Physiological Processes Limiting Plant Productivity*, 147 - 158, London: Butterworths.

Sestak, Z., Catsky, J. and Jarvis, P.G. 1971: Criteria for the selection of suitable methods. In. *Plant Photosynthetic Production Manual of Methods*. (eds. Sestak, Z., Catsky, J. and Jaevis, P. G.), The Hague, Junk. pp 1 - 48.

Sethu, Ponnammal, Paliwal, Kailash and Gnanam, A. 1985 : Some physiological observations in a two year old *Leucaena* plantation. *Leucaena Research Reports* 6: 53.

Shaner, D. L. and Boyer, J. S. 1976: Nitrate reductase activity in maize (*Zea mays* l.) leaves. II. Regulation by nitrate flux at low leaf water potential. *Plant Physiol.* 58: 505 - 509.

Sharma, A. K. 1994 : Performance of subabul (Hawaiian Giant K8) under different management systems in the Andaman Islands. In (Singh, P., Pathak, P.S. and Roy, M.M. eds.) *Agroforestry Systems for Degraded Lands* 1: 308 - 313, Oxford & IBH Pub. Co. Ltd., New Delhi.

Sharma, E. amd Ambasht, R. S. 1987: Litter fall, decomposition and nutrient release in an age sequence of *Alnus nepalensis* plantation stands in the eastern Himalaya. *J. Ecol.* 75: 997 - 1010.

Sharma, U. S., Sharma, S., Sharma, S. D., Upadhyay, S. D. and Nigam, P. K. 1994: Seed dormancy in relation to pod maturity of *Leucaena leucocephala. Nitrogen Fixing Tree Research Reports* 12: 111 - 113.

Shelton, H. M. and Brewbaker, J. L. 1994 : *Leucaena leucocephala* - the most widely used forage tree legume. In (Gutteridge, R. C. and Shelton, H. M. eds.) *Forage Tree Legumes in Tropical Agriculture*. 15 - 29.

Shimsi, D. 1970: The effect of nitrogen supply on some indices of plant water relations of beans (*Phaseolus vulgaris* L.). *New Phytol.* 69: 413 - 424.

Shimsi, D. and Kafkafi, U. 1978: The effect of supplemental irrigation and nitrogen fertilization on wheat (*Triticum aestivum* L.). *Irrigation Science* 1: 27 - 38.

Shinozaki, K., Yoda, K., Hozumi, K. and Kira, T. 1964a: A quantitative analysis of plant form - the pipe model theory. I. Basic analysis. *Japanese J. Ecol.* 14: 97 - 105.

Shinozaki, K., Yoda, K., Hozumi, K. and Kira, T. 1964b: A quantitative analysis of plant form - the pipe model theory. II. Further evidence of the theory and its application in forest ecology. *Japanese J. Ecol.* 14: 133 - 139.

Shreve, F. 1942: The desert vegetation of north America. *Bot. Rev.* 8: 195 - 246.

Shukla, R. P. and Ramakrishnan, P. S. 1982: Phenology of trees in a sub - tropical humid forest in north eastern India. *Vegetatio* 49: 103 - 109.

Siffel, P., Santrucek, J., Lang, M., Braunova, Z., Sumkova, M., Synkova, H. and Licntenthaler, H. K. 1993: Age dependence of photosynthetic activity, chlorophyll fluorescence parameters and chloroplast ultra structure in aurea and green forms of *Nicotiana tabacum* Su / su mutant. *Photosynthetica* 29 (1): 81 - 94.

Sims, P. L. and Singh, J. S. 1971: Herbage dynamics and net primary production in certain ungrazed and grazed grasslands in north America. In: *Priliminary Analysis of Structure and Function in Grasslands*, Range Science Dept., Science Series No. 10, pp 59 - 113, Fort Collins, U S A,

Colorado State University.

Singh, A. K. 1972: Structure and primary net production and mineral contents of two grassland communities of Chakia hills, Varanasi, Ph. D. thesis, Banaras Hindu University, Varanasi, India.

Singh, J. S. and Gupta, S. R. 1977: Plant decomposition and soil respiration in terrestrial ecosystems. *Bot. Rev.* 43: 449 - 529.

Singh, J. S. and Joshi, M. C. 1979: Primary production in tropical grasslands, In: *World Grassland Ecosystems, 197 - 218* (ed. Coupland , R. T.), Cambridge University Press, London.

Singh, J. S. and Misra, R. 1968: Efficiency of energy capture by grassland vegetation of Varanasi, *Current Science* 37: 636 - 637.

Singh, J. S. and Yadava, P. S. 1973: Caloric values of important plant and insect species of tropical grasslands, *Oikos* 24: 186 - 194.

Singh, K. P. 1968: Litter production and nutrient turn over in deciduous forests of Varanasi, In: *Proceedings of the Symposium on Recent Advances in Tropical Ecology* 655 - 665, (eds. Misra, R. and Gopal, B.), International Society for Tropical Ecology, Varanasi, India.

Singh, K. P. 1989 : Structure and functioning of Indian forest ecosystems, In : (Singh, J. S. and Gopal, B. eds.) *Perspectives in Ecology* 411 - 427, Jagmander Book Agency, New Delhi.

Singh, K. P. and Misra, R. 1978: Structure and functioning of natural, modified and silvicultural ecosystems in eastern Uttar Pradesh, Final Tech. rep. (1975 - 78), MAB Research Project 1, Banaras Hindu University, Varanasi, India. 161 pp.

Singh, N. T. 1992 : Dryland salinity in the Indo - Pakistan sub - continent. In (Dregne, H. E. ed.) *Degradation and Restoration of Arid Lands*. International Centre Arid and Semi-arid Land Studies, Texas Tech. University, USA, pp 179- 248.

Singh, Panjab 1994: Land degradation - a global menace and its improvement through agroforestry. In (Singh, Panjab, Pathak, P. S. and Roy, M. M. eds.) *Agroforestry Systems for Sustainable Land Use*, 4 - 20, Oxford & IBH Pub. Co. Ltd., New Delhi.

Singh, R. L. (ed.) 1971 : *India - A Regional Geography*, Silver Jubilee Publication, National Geographical Society of India, Varanasi, 992 p.

Singh, R. P. 1974: A study of primary productivity and nutrient cycling in Chakia forest, Varanasi. Ph. D. thesis, Banaras Hindu university, Varanasi, India.

Singh, R. P. 1979: Primary production and energy dynamics of tropical deciduous forests in Chandraprabha region, Varanasi. Ph. D. Thesis, Banaras Hindu University, Varanasi, India.

Singh, S. 1994: Physiological response of different crop species to low light stress, *Indian J. Plant Physiol.* XXXVII (3): 147 - 151.

Singh, S. N. 1988: Primary productivity and nutritive value of two important grasses of Gangetic plain in Bihar, Ph. D. thesis, Magadh University, Bodh Gaya, pp.218.

Singh, U. N., Srivastava, V. K. and Senger, R. B. S. 1982: A comparative study of the rate of dry matter production in forest tree seedlings (*Diospyros montana* Roxb. and *Buchnania latifolia* Roxb.), *The J. of Forestry* 5(1): 8 - 40.

Slatyer, R. O. and Morrow, P. A. 1977: Altitudinal variation in the photosynthetic characteristics of snow gum, *Eucalyptus pauciflora* sieb. ex spreng. I. Seasonal changes under field conditions in the snowy mountains area of south eastern Australia, *Australian J. Bot.* 25: 1 - 20.

Slatyer, R. O. 1967: *Plant Water Relationships*, Academic Press, New York, London.

Sorensen, T. 1941: Temperature relations and phenology of the north east greenland flowering plants. *Medd. Gronland* 125: 1 - 305.

Spain, A. V. 1984: Litter fall and the standing crop of litter in three tropical Australian rain forests, *J. Ecol.* 72: 947 - 961.

Squire, G. R., Marshall, B., Terry, A. and Monteith, J. L. 1984: Response to temperature in a stand of pearl millet, 6. Light interception and dry matter production. *J. Experimental Botany* 35: 599 - 610.

*Srivastava, H. S. 1980: *Phytochemistry* 19: 725 - 733.

Srivastava, S. K., Singh, K. P. and Upadhyay, R. S. 1986 : Fine root growth dynamics in teak (*Tectona grandis* Linn. f.) *Canadian J. Forest Res.* 16: 1360 - 1364.

Strain, B. R., Higginbotham, K. O. and Mulroy, J. C. 1976: Temperature preconditioning and photosynthetic capacity of *Pinus taeda* L. *Photosynthetica* 10: 47 - 53.

Stuart, Chapin F. 1980: The mineral nutrition of wild plants. *Ann. Rev. Ecol. & Syst.* 11: 233 - 260.

Sundriyal, R. C., Joshi, A. P. and Dhasmana, R. 1987: Phenology of high altitude plants at Tungnath in the Garhwal Himalaya. *Trop. Ecol.* 28: 289 - 299.

Sundriyal, R. C. 1990: Phenology of some temperate woody species of the Garhwal Himalaya, *Int. J. Ecol. Environ. Sci.* 16(2 - 3): 107 - 117.

Survey of Indian Agriculture. 1994, pp. 216, The Hindu.

Swarnkar, Vandana 1996 : Physiological adaptability, growth behaviour and regeneration of sesbania species. Ph. D. Thesis, Bundelkhand University, Jhansi, 1 - 254.

Swasdiphanich, S. 1992 : Environmental influences on forage yields of shrub legumes, Ph. D. thesis, The University of Queensland.

Szarek, S. R. and Woodhouse, R. M. 1976: Ecophysiological studies of sonoran desert plants. 1. Diurnal photosynthesis patterns of *Ambrosia deltoidea* and *Olneya tesota, Oecologia* 26: 225.

Tagayava, S. V. and Brandt, A. B. 1960 : Study of the optical properties of leaves in relation to the angle of incidence of light. *Biofizika* 5: 308 - 317.

Teal, J. M. 1957 : Community metabolism in a temperate cold spring. *Ecol. Monograph* 27: 283 - 302.

Tewari, D. N. 1994 : Agroforestry for sustainable development. In ((Singh, Panjab, Pathak, P. S. and Roy, M. M. eds.) *Agroforestry Systems for Degraded Lands*, 2: 835 - 848, Oxford & IBH Pub. Co. Ltd., New Delhi.

*Thapliyal, P., Nautiyal, A. R. and Purohit, A. N. 1986 : *Proc. Bioenergy Soc. Conv. & Symp.* 2 : 79 - 86.

Thornely, J. H. M. 1972 : A balanced quantitative model of root : shoot ratios in vegetative plants. *Ann. Bot.* 36 : 431 - 441.

Tieszen, L. L. and Johnson, P. L. 1968 : Pigment structure of some arctic tundra communities. *Ecology* 49 : 370 - 373.

Toky, O. P. and Ramakrishnan, P. S. 1983: Secondary succession following slash and burn agriculture in north eastern India. I. Biomass, litterfall and productivity. *J. Ecol.* 71: 735 - 745.

Tomlinson, P. B. and Gill, A, M. 1973: Growth habits of tropical trees: some guiding principles. *Tropical Forest Ecosystems in Africa and South America : A comperative Review* (eds. Meggers, B. J., Ayensu, E. S. and Duckworth, W. D.) : 129 - 143, Smithsonian Institution Press, Washington D.C.

Tranquillini, W. 1957: Standortklima, wesserbilanz und CO2 Gaswechsel junger Zirben and der alpinen Waldrenze. *Planta* 49: 612 - 661.

*Tranquillini, W. 1969: *Zintbl. ges Fortw* 86: 35.

*Tregunna, E. B., Krothkov, G. and Nelson, C. D. 1966: *Physiologia Pl.* 19: 723.

Troll, W. 1937: *Vergleichende Morphologie der Hohernen,* Band I, teil 1. Berlin: Borntraeger.

Upadhyay, V. S., Rekib, A. and Pathak, P. S. 1974 : Nutritive value of *Leucaena leucocephala, Indian Vet. J.* 51 : 534 - 537.

Vandana and Bhatt, R. K. 1996 ; Seasonal variation in CO_2 exchange, transpiration and stomatal conductance in *Sesbania. Photosynthetica* 32(2): 277 - 279.

Van den Beldt, Rick J. 1982 : Litter fall as function of population in a one year old *Leucaena* (K8) planting. *Leucaena Research Reports* 3: 95.

Van den Beldt, Rick J., Brewbaker, J. L., Hu, Ta-we and Boontawee, Boon Choob. 1982 : International *Leucaena* population trials, *Leucaena Research Reports* 3: 96 - 99.

Van Groendael, J. M. 1985: Teratology and metameric plant construction. *New Phytologist* 99: 171 - 178.

Visalakshi, N. 1993: Litter fall, standing crop of litter and their nutrients in two tropical dry evergreen forests in India. *International J. Ecology & Environmental Sciences* 19: 163 - 180.

Vyas, L. N., S. K. Agrawal and Garg, R. K. 1972; Biomass production by deciduous trees in Rajasthan. *Erythrina suberosa* Roxb. In (Golley, P. and Golley, F. B. eds.): *Trop. Ecol. with emphasis on*

Organic Production, 195 - 200.

Walter, H. 1968: *Die vegetation der Erde in Oeko physiologischer Betrachtung.* Vol. 2, Fisher, Stuttgart.

Wardlaw, I. F. 1969: The effect of water stress on translocation in relation to photosynthesis and growth. II. Effect during leaf development in *Lolium temulenthum* L. *Aust. J. Biol. Sci.* 22: 1.

Waring, R. H. and Running, S. W. 1970 : Water uptake, storage and transpiration by conifers- a physiological model. *Ecological Studies* 19: 189 - 202.

Wassink, E. C. 1959: Efficiency of light energy conversion in plant growth. *Plant Physiology* 3(4): 356 - 361.

Weeraratna, C. S. 1982 : Nitrogen release during decomposition of *Leucaena* leaves. *Leucaena Research Reports* 3: 54.

Went, F. W. and Stark, N. 1968: Mycorrhiza, *Bioscience* 18: 1035 - 1039.

Westlake, D. F. 1963 : Comparisons of plant productivity. *Biol. Rev.* 38: 385 - 425.

Whittaker, R. H. 1975: *Communities and Ecosystems.* 2nd edition, Mac millan, new York 385p.

Whitmore, T. C. 1984: *Tropical Rain Forests of the Far East.* 2nd edition, Clarendon press, Oxford. *

Willis, A. J., Yemm, E. W. and Balasubramaniam, S. 1963: Transpiration phenomenon in detached leaves, *Nature,* 199: 265 - 266.

Wilson, D. and Cooper, J. P. 1969: Effect of light intensity during growth on leaf anatomy and subsequent light saturated photosynthesis among constrating *Lolium* genotypes. *New Phytol.* 68: 1125.

Wright, R. D. 1970: CO_2 exchange of seedlings of pines in the laboratory as related to lower elevational limits. *Am. Midland Natur.* 83: 291 - 300.

Yarwood, C. F. 1961: Acquired tolerance of leaves to heat. *Science* 134: 941 - 942.

Yemm, E. W. and Willis, A. J. 1954: Stomatal movements and changes of carbohydrates in leaves of *Chrysanthemum maximum. New Phytol.* 53: 373 - 396.

Zahner, R. 1968: Water deficit and growth of trees. In (Kozlowski, T. T. ed.): *Water Deficit and Plant Growth,* Vol. 2: 191 - 254, Academic Press, New York.

Zimmermann, M. and Brown, C. L. 1971: *Trees : Structure and Function,* Springer - Verlag, New York.

* Not seen in original.